Task Completion Report

Task 4-0017

Cache la Poudre Streamflow Regulation Accounting Modeling

submitted to

National Weather Service/NOAA
1325 East West Highway, Room 9434
Silver Spring, Maryland 20910
301-713-1658

by

Riverside Technology, inc.
Water Resources Engineering and Consulting

2290 East Prospect Road, Suite 1
Fort Collins, Colorado 80525
970-484-7573

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TABLE OF CONTENTS

Section

Figures

Tables

1.0 INTRODUCTION

As part of an effort to provide Advanced Hydrologic Prediction Services (AHPS), the National Weather Service (NWS) is using the NWS River forecast system (NWSRFS) to prepare probabilistic forecasts of streamflow several months into the future. The presence of extensive systems of streamflow regulation to capture and divert runoff in many parts of the country will require additional effort and perhaps new procedures to characterize and accurately predict the effect of this regulation for developing long-range forecasts.

The Missouri Basin River Forecast Center (MBRFC) is responsible for forecasting many basins where streamflow regulation is substantial, and has worked in conjunction with Riverside Technology, inc. (RTi) to evaluate existing data sources and modeling approaches and develop a generalized strategy to account for regulation in long-range forecasts. This study has focused on the South Platte river basin above North Platte, Nebraska, but the results have broad applicability for regions outside of the MBRFC where regulation is an issue. A culminating element of the study will be a demonstration implementation and evaluation of strategies identified earlier in the study. The first task of the study (Task No. 3-0001) was completed by RTi. That task provided the groundwork for the demonstration implementation and evaluation by: soliciting and compiling feedback from RFCs regarding significant regulation and management issues and solutions; developing modeling strategies, an implementation plan, and an evaluation plan for the South Platte basin that will be consistent with national needs and interests; and identifying and collecting initial data for the implementation.

The current task No. 4-0017 is the second task associated with streamflow regulation accounting and consists of the actual implementation of the South Platte Implementation Strategy (SPIS) developed as part of the first task order. The Cache la Poudre basin was identified as the initial South Platte River sub-basin to apply NWSRFS technologies and procedures where regulation has significant impacts because RTi staff had significant experience and knowledge pertaining to the water management practices in the Cache la Poudre basin, and large amounts of data were available concerning regulations in the basin. This implementation serves as a test basin to evaluate the strategies and identify limitations in data, procedures, and technologies for ultimate application in other parts of the South Platte Basin as well as in other parts of the country. Future phases will consist of implementing the strategy with any necessary revisions in other parts of the South Platte Basin where there are fewer data and information characterizing the streamflow regulation.

The objective of this task order was to implement the SPIS for the Cache la Poudre River Basin, and to evaluate the effectiveness of the approach in modeling basin streamflow regulation. RTi completed the following activities:

- Identified, implemented, and tested three modeling approaches for accounting for major basin regulation activities. The first approach consisted of basin simulation without any accounting of streamflow regulation. The second approach used aggregated historical records of imports, diversions, return flows, and reservoir releases to characterize streamflow regulation in a long-range ensemble-forecasting mode. The third approach modeled regulation by simulating demand, diversions, storage, release, and return flows based on model states and inputs using a variety of combinations of NWSRFS operations. The approaches were developed and selected based on sound science, current and planned NWSRFS capabilities, and an awareness of the resources required for development, operation, and maintenance of the approaches.
- Compared a suite of sample 90-day probabilistic forecast products for the three approaches.

- Evaluated the effectiveness of the three approaches by generating forecast verification statistics using hindcasting in the NWS Ensemble Streamflow Prediction Verification System (ESPVS) and comparing the results for each approach.
- Reviewed and evaluated general strategies for modeling regulation based on the experiences of modeling the Cache la Poudre basins and made recommendations for future phases and development activities in basins with substantial regulations.

1.1 Modeled Area

Figure 1-1 shows a map of the Cache la Poudre River with the delineated MBRFC sub-basins. The sub-basin delineations provided by the MBRFC are overlain on a Digital Elevation Model (DEM). This map also shows the precipitation and temperature stations used to generate mean areal precipitation (MAP) and temperature (MAT) time series. Sub-basin information is included in ***Table 1-1***.

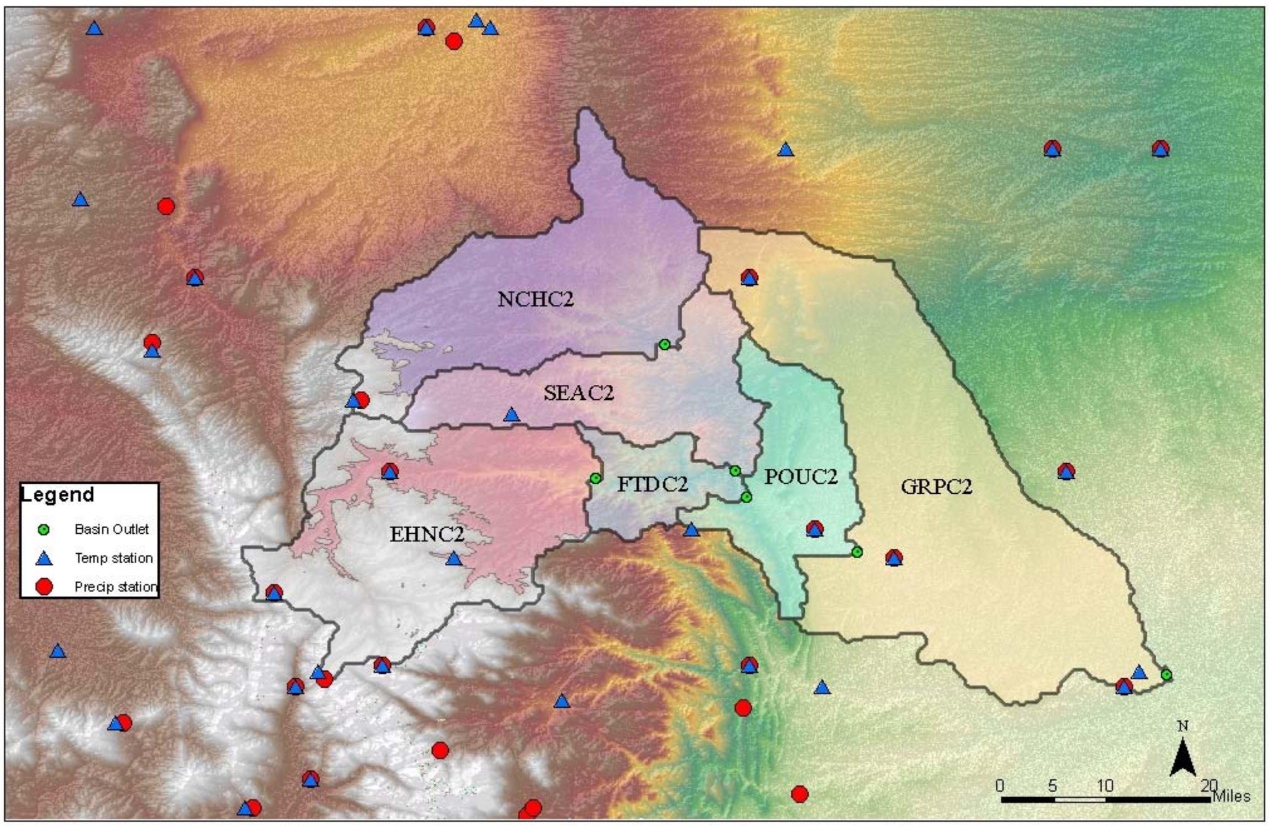

Figure 1-1. Cache la Poudre River sub-basin delineations

Table 1-1. Cache la Poudre River sub-basin characteristics

Basin ID	USGS Station Number	Sub-Basin Name	Area (mi^2)	Ratio of Upper/Lower Elev Zone Areas
EHNC2	06749000	Poudre R. below Elkhorn Creek	399	0.55/0.45
NCHC2	06751150	N. Poudre R. below Halligan Res.	347	0.08/0.92
SEAC2	(no USGS gage)	N. Poudre R. below Seaman Res.	209	N/A
FTDC2	06752000	Poudre R. at Canyon Mouth	79	N/A
POUC2	06752260	Poudre R. at Lincoln St, Fort Collins	163	N/A
GRPC2	06752500	Poudre R. at Greeley	655	N/A

The natural flows of the Poudre River are subject to regulations of various forms by a variety of users throughout the basin. Trans-basin imports transport water from the adjacent Colorado and Laramie River basins into the EHNC2 and NCHC2 sub-basins. The Colorado-Big Thompson project provides water to Horsetooth Reservoir that is used for municipal and agricultural use throughout the lower sub-basins. A number of reservoirs in EHNC2 store and release water throughout the year. Halligan Reservoir and Seaman Reservoir provide streamflow regulation on the North Fork of the Poudre. A major canal diverts the majority of the flows exiting Halligan Reservoir to a group of small reservoirs located in the plains downstream of the FTDC2 outlet. The majority of the diversions from the river occur downstream of the Canyon Mouth stream gage (FTDC2). Almost all of the flows downstream of FTDC2 are diverted and re-diverted several times before reaching the city of Greeley (GRPC2). Agricultural and municipal return flows comprise most of the local area contribution downstream of FTDC2. The net effects of the regulation occurring in the basin provide a complicated backdrop and create unique challenges for modeling the streamflow in the basin. The streams, canals, and lakes/reservoirs located throughout the basin can be seen in the following map (***Figure 1-2***).

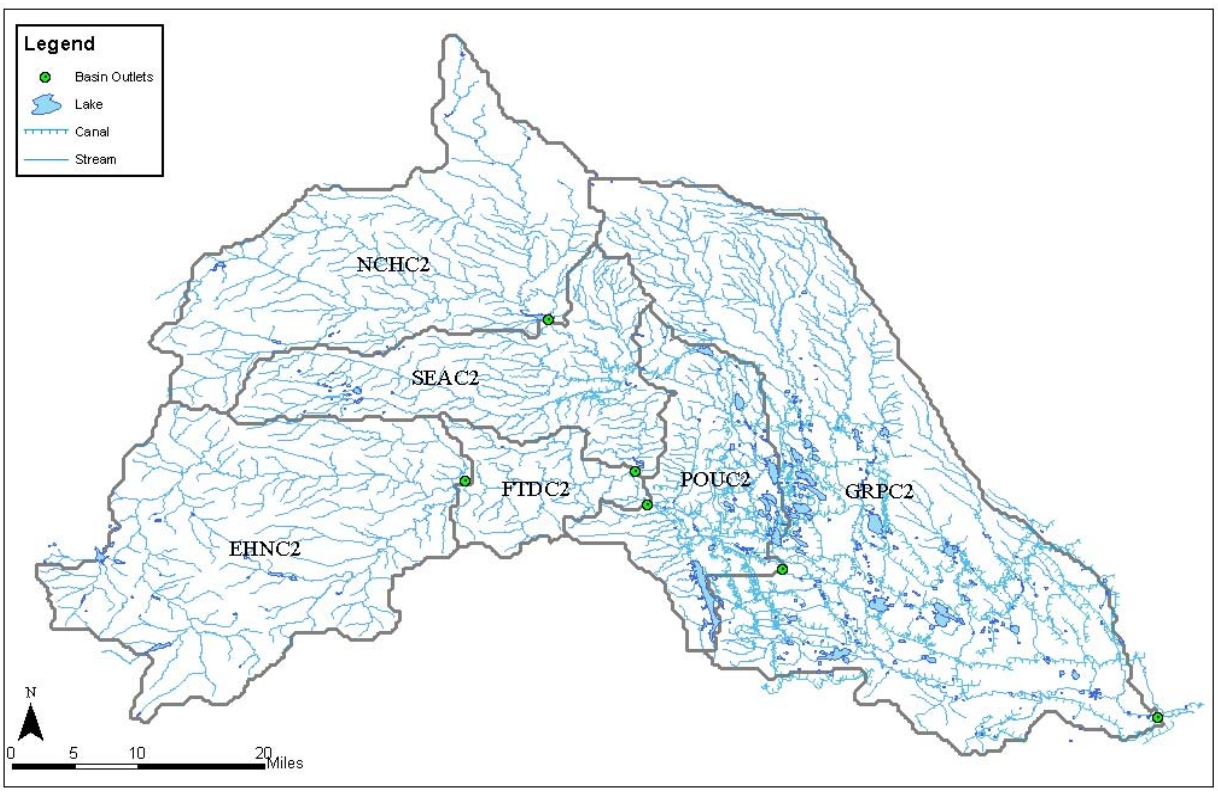

Figure 1-2. Poudre River Hydrology

2.0 DATA ANALYSIS AND QA/QC

A number of preprocessing steps were required before calibrating or implementing the three different modeling approaches, including data collection, flow naturalization, and a water balance analysis.

2.1 Required Data

A large amount of data and information were collected throughout the course of this project. The MBRFC provided RTi with MAP and MAT estimates for each sub-basin and each elevation zone of the sub-divided sub-basins. The MAP and MAT time series were generated for the period of 10/1978 – 9/2003. Unit hydrographs were also generated by the MBRFC and provided to RTi. A 30-meter National Elevation Dataset (NED) DEM, 30-meter National Land Cover Dataset (NLCD), and National Hydrology Dataset (NHD) hydrology coverage were all downloaded from the United States Geological Survey (USGS). Regulation information and data were obtained primarily from Hydrobase, a database of streamflow and regulation measurements for the state of Colorado. Information concerning regulation practices was obtained through meetings with various water management agencies in the Poudre River basin. All of this information was used to develop appropriate modeling strategies for the basin.

2.2 Regulation Time Series and Flow Naturalization

In modeling Approach 1, the effects of regulation needed to be removed from the streamflow time series to allow calibration of natural runoff response using snow and soil moisture accounting models. In Approach 2, the effects of regulation are accounted for using observed regulation time series. Finally, in Approach 3, the regulation effects are modeled using other model states. In order to accomplish each of these approaches, data for each major regulation needed to be collected and organized. After collecting the data, the regulations were aggregated and used to generate a time series of net regulation in each sub-basin for Approach 2. The regulation data were then used to remove the effects of the regulation from the observed streamflow at each outlet point for Approach 1. The regulation time series were also used as observed time series for calibration of the various models used in Approach 3.

2.2.1 Regulation Data Collection

The first step toward generating the natural flow time series was to gather a list of all recorded diversion, reservoir, and streamflow identifiers for data extraction from the Hydrobase database. In Hydrobase, data are stored by identifier (ID) and by the Source, From, Use, and Type (SFUT) codes. The SFUT codes are used by the water commissioners to differentiate the water for accounting purposes. Each diversion and reservoir was examined to determine appropriate SFUT codes to obtain the proper data for use in this study. All data extracted from Hydrobase were available on a daily time step. The RTi software package TSTool was used to extract, view, plot, and manipulate data from Hydrobase in this and subsequent steps. This facilitated the eventual generation of NWS CARD data files for use in calibration.

During the data collection and flow naturalization process, the data were reviewed for consistency and quality. The majority of the regulations were available in Hydrobase for the entire period that MAP and MAT data were generated. However, the trans-basin imports were not recorded in Hydrobase before May 1986, which limited the period of analysis. The data quality through 1987 was generally poorer, including no release observations at Seaman Reservoir until 1988. During the calibration phase, the analysis period was set to October 1987 – September 2003. During the data extraction and flow naturalization, however, data were collected and manipulated beginning in January 1971.

Data for a number of regulations were either unavailable in Hydrobase or were stored under alternate identifiers. Many times, when the initial ID did not yield the desired data, the data were being assigned to the upstream or downstream reservoirs instead of the main river inlet or outlet structure.

In Hydrobase, the Hansen Supply Canal (ID 909) contains only a partial data record. Further investigation revealed that much of the Hansen Supply Canal data was stored under the Streamflow source ID HSCCLPCO as opposed to Diversion ID 909.

Flows below Seaman Reservoir were not available in the Hydrobase database, although the gage is operated by the state. The Seaman Reservoir data were eventually obtained from the Poudre River water commissioner.

During analysis of the FTDC2 naturalized flows, it became clear that certain regulation effects in or near the month of October were not removed. Further analysis revealed that the water commissioners release water from the upstream reservoirs in the EHNC2 sub-basin to draw down these reservoirs before the winter freeze. This water is diverted downstream at the Poudre Valley Canal for storage in the lower reservoirs. Although the diversions at the canal were recorded in Hydrobase, the releases from the upstream reservoir were not. An artificial time series representing these late-season reservoir releases from EHNC2 was created based on the corresponding downstream diversions at the Poudre Valley Canal.

The USGS gage below Halligan Reservoir began operation in March 1998. A longer period of record was desired for this location for both the historic and naturalized flow calibrations. A downstream USGS gage at Livermore has collected data since October 1986, although there is a significant diversion (the North Poudre Canal) between the Halligan and Livermore gages. A record of diversions was available for this diversion from Hydrobase. After adding back in the diversion to the Livermore flows, the Halligan and Livermore records were correlated and the resulting monthly linear regressions were used to fill the Halligan streamflow record for the period 10/86 – 3/98.

One final difficulty involved the accounting of water treatment plant releases from municipal projects on the lower end of the Poudre River. These flows individually were not considered significant, but in aggregate could have an impact on natural flow computations and total flow simulations during low flow conditions. The only data available for these releases were total monthly values for limited time periods. The monthly values were filled for the full period of record by either repeating the average monthly flow over the reported years for those years that were missing or increasing the flows from the last reported year by a percentage to represent increases in serviced population. Those water treatment plant releases that no longer enter the river at a given location were filled with zeroes after their termination. Since all other regulation data were available on a daily time interval, the monthly flow data were distributed uniformly across each month to produce a daily flow time series. Because of the uniform nature of the water treatment plant releases and relatively small size of these flows, the affect of distributing the monthly flows to a daily time step was not large.

2.2.2 Aggregation of Regulations

For the second modeling approach, the effects of regulation were aggregated together within each sub-basin and used to represent the effects of regulation for long-range ensemble streamflow forecasting. The aggregated regulation time series were also used for the regulation model calibration in the third modeling approach.

Computed stream lengths were used to determine travel times between regulations and sub-basin outlets. Regulations with similar travel times were grouped together. The regulations were further grouped according to regulation type. Finally, the diversions for the water treatment plants and wastewater treatment plants in the POUC2 and GRPC2 sub-basins were kept as separate time series for modeling purposes. TSTool was used to aggregate the appropriate time series and generate CARD data files for each aggregated time series.

Table 2-1, ***Table 2-2***, and ***Table 2-3*** list all of the regulations in the Poudre River basin, their corresponding Hydrobase ID's, and the aggregated time series that each regulation is a part of. The regulations were classified into five major groups:

1) Trans-basin Imports: Water imported from adjacent basins into the Poudre basin (***Table 2-1***).
2) Diversions to Reservoir Storage: Water diverted to/stored in reservoirs. This is water that remains in the reservoirs for some period of time and excludes any water that passes into and immediately out of the reservoir, causing no net change in reservoir storage contents (***Table 2-1***).
3) Reservoir Releases from Storage: Stored water released from reservoirs. This does not include any water simply passing through the reservoir without being stored (***Table 2-1***).
4) Diversions to Structures: Diversions from the river at a structure (usually but not always for agricultural purposes; ***Table 2-2***).
5) Releases from Wastewater Treatment Plants: Time series generated from monthly total flow volumes representing the releases to the river from municipal and industrial wastewater treatment facilities (***Table 2-3***).

After generating the appropriate CARD data files for every aggregated time series, the aggregated regulations were combined to create a time series of the net regulation in each sub-basin. Regulations in the upper portions of the sub-basins were routed downstream using routing parameters computed as described in ***Section 3.2***. The net regulation time series for each sub-basin was generated using the NWSRFS manual calibration program (mcp3).

Table 2-1. Poudre River regulations and aggregated time series: import and reservoir data

TransBasin Imports		
Hydrobase ID	**Name**	**Aggregated Time Series**
909	Hansen Supply Canal	POUC2_Upper_Imp
HSCCLPCO	Hansen Supply Canal	POUC2_Upper_Imp
4600	Laramie-Poudre Tunnel	EHNC2_Imp
4601	Grand River Ditch	EHNC2_Imp
4602	Cameron Pass Ditch	EHNC2_Imp
4603	Michigan Ditch	EHNC2_Imp
4604	Wilson Supply Ditch	NCHC2_Upper_Imp
4605	Skyline Ditch	EHNC2_Imp
4606	Bob Creek Ditch	EHNC2_Imp

Diversions to Reservoir Storage		
Hydrobase ID	**Name**	**Aggregated Time Series**
3676	Long Draw Reservoir	EHNC2_DivStor
3677	Peterson Reservoir	EHNC2_DivStor
3678	Joe Wright Reservoir	EHNC2_DivStor
3679	Chambers Reservoir	EHNC2_DivStor
3683	Barnes Meadow Reservoir	EHNC2_DivStor
3684	Twin Lakes Reservoir	EHNC2_DivStor
3686	Commanche Reservoir	EHNC2_DivStor
3712	Halligan Reservoir	NCHC2_Lower_DivStor
3713	Seaman Reservoir	SEAC2_DivStor
3720	Hourglass Reservoir	EHNC2_DivStor
3726	Worster Reservoir	NCHC2_Upper_DivStor
3754	Twin Lakes	EHNC2_DivStor
3774	Fossil Creek Reservoir	GRPC2_Upper_DivStor

Reservoir Releases from Storage		
Hydrobase ID	**Name**	**Aggregated Time Series**
3676	Long Draw Reservoir	EHNC2_Rel
3677	Peterson Reservoir	EHNC2_Rel
3678	Joe Wright Reservoir	EHNC2_Rel
3679	Chambers Reservoir	EHNC2_Rel
3683	Barnes Meadow Reservoir	EHNC2_Rel
3684	Twin Lakes Reservoir	EHNC2_Rel
3686	Commanche Reservoir	EHNC2_Rel
3712	Halligan Reservoir	NCHC2_Lower_Rel
3713	Seaman Reservoir	SEAC2_Rel
3720	Hourglass Reservoir	EHNC2_Rel
3726	Worster Reservoir	NCHC2_Upper_Rel
3754	Twin Lakes	EHNC2_Rel
3774	Fossil Creek Reservoir	GRPC2_Middle_Rel
3780	Claymore Lake Reservoir	POUC2_Lower_Rel
907	EHNC2 Artificial Oct Release	EHNC2_ArtRel

Table 2-2. Poudre River regulations and aggregated time series: diversion data

Diversions to Structures		
Hydrobase ID	**Name**	**Aggregated Time Series**
220	Fox Acres	NCHC2_Lower_Div
905	North Poudre Supply Canal (aka Munroe)	FTDC2_Div
906	Fort Collins Pipeline	FTDC2_Div906-WTP
907	Poudre Valley Canal	FTDC2_Div
908	Greeley Filter Intake	POUC2_Div908-WTP
910	Pleasant Valley & Lake Canal	POUC2_Upper_Div
911	Larimer County Canal	POUC2_Upper_Div
912	Jackson Ditch	POUC2_Lower_Div
913	New Mercer Canal	POUC2_Lower_Div
914	Larimer County Canal No.2	POUC2_Lower_Div
915	Little Cache la Poudre Ditch	POUC2_Lower_Div
916	Claymore Outlet	POUC2_Lower_Div
918	Arthur Ditch	POUC2_Lower_Div
919	Larimer and Weld Canal	POUC2_Lower_Div
921	Josh Ames Ditch	POUC2_Lower_Div
922	Lake Canal	POUC2_Lower_Div
923	Coy Ditch	POUC2_Lower_Div
925	Chaffee Ditch	GRPC2_Upper_Div
926	Boxelder Ditch	GRPC2_Upper_Div
929	Greeley No. 2 Canal	GRPC2_Middle_Div
930	Whitney Ditch	GRPC2_Middle_Div
931	BH Eaton Ditch	GRPC2_Middle_Div
932	Jones Ditch	GRPC2_Lower_Div
934	Greeley No.3 Canal	GRPC2_Lower_Div
935	Boyd Freeman Ditch	GRPC2_Lower_Div
937	Ogilvy Ditch	GRPC2_Lower_Div
994	North Poudre Canal	SEAC2_Div
995	William Calloway Ditch 1	SEAC2_Div
996	William Calloway Ditch 2	SEAC2_Div
997	Chase Ditch	SEAC2_Div
1029	Taylor & Gill	POUC2_Lower_Div
1038	Burnham	NCHC2_Lower_Div
1039	Mitchell	NCHC2_Lower_Div
1041	Wetzler	NCHC2_Lower_Div
3775	Timnath Inlet	GRPC2_Upper_Div

Table 2-3. Poudre River regulations and aggregated time series: WWTP and streamflow data

Wastewater Releases Generated from Monthly Total Volumes		
Hydrobase ID	**Name**	**Aggregated Time Series**
N/A	Fort Collins WWTP1	GRPC2_Upper_RelWWTP
N/A	Fort Collins WWTP2	GRPC2_Upper_RelWWTP
N/A	Greeley Lower WWTP	GRPC2_Lower_RelWWTP
N/A	Greeley 23rd St. WWTP	GRPC2_Lower_RelWWTP
N/A	Boxelder WWTP	GRPC2_Lower_RelWWTP
N/A	Kodak WWTP	GRPC2_Lower_RelWWTP
N/A	Windsor WWTP	GRPC2_Lower_RelWWTP
N/A	Greeley WWTP	GRPC2_Lower_RelWWTP

Streamflow Time Series		
Hydrobase ID	**Name**	**Aggregated Time Series**
06751490	Livermore	N/A
06752000	Canyon Gage	N/A
06751150	Below Halligan	N/A
06752260	Fort Collins (Lincoln Street)	N/A
06752500	Greeley	N/A

2.2.3 Flow Naturalization

After compiling regulation information, the effects of the regulations could be removed from the observed streamflow time series. No streamflow data were available for the EHNC2 sub-basin. For NCHC2, SEAC2, and FTDC2, total natural flow time series were generated. These were computed as:

Total Natural Q = Observed Q – Imports + Diversions to Storage – Releases from Storage + Diversions

The routing of regulation effects downstream was neglected in the flow naturalization for the upper sub-basins. The total travel times in the upper sub-basins are around 6 hours.

For the downstream sub-basins, the local area natural flow contribution was computed instead of total natural flows because of the greater travel times involved. These were computed as:

Local Natural Q = Downstream Obs Q – (lagged) Upstream Q – Imports + Diversions to Storage – Releases from Storage or WWTP + Diversions

In the FTDC2 sub-basin, the routing from FTDC2 to POUC2 was neglected, as the travel time is typically less than 6 hours. In the GRPC2 sub-basin, a 24-hour lag time of the upstream observed flow was included in the computations. All flow naturalization computations were completed using TSTool.

The above computations account for all observable regulation effects. However, non-point agricultural return flows are not measured and are thus neglected. In the upper sub-basins, there is very little agricultural activity and negligible agricultural return flows. In the lower sub-basins (POUC2 and GRPC2), however, there is substantial irrigation and subsequent return flows. Therefore, the naturalized flows for these sub-basins include both local runoff contributions as well as agricultural return flows. The downstream computed naturalized flows were used in conjunction with the local area simulations to estimate agricultural return flows as described in ***Section 4.1***.

2.2.4 Quality Control of Regulation Grouping and Flow Naturalization

As a quality control check, the net regulation time series created for each sub-basin were added to the naturalized flow time series and compared with the total flow time series at each outlet point using NWSRFS calibration decks to assure all time series were accounted for in both processes. This quality control step revealed some errors made during the naturalization and flow aggregation process that were corrected before completing the analyses.

A number of different studies have been conducted to quantify the effects of irrigation on a monthly time step in the Poudre River basin and generate monthly time series of naturalized flows at different points in the basin. The Northern Integrated Supply Project (NISP) study was used as a baseline of comparison during the natural flow analysis and as a quality control check of the computations. The final naturalized flow time series compare well with the published NISP monthly-naturalized flows over the analysis period.

2.3 Naturalized Flow Water Balance Analysis

A naturalized water mass balance was computed over the period 10/1987 – 9/2003 for the Poudre River sub-basins to aid in the natural flow calibration and to provide an overall consistency check of the data. The water balance was limited to this period because of lower data quality before October 1987. The water balance analysis can help in identifying potential problems in the observed data that could affect the calibration phase. Inconsistencies in MAP or PET are sometimes evident in the comparison of sub-basin characteristics. In computing the overall water mass balance, estimates of average annual natural flow volume, MAP, and PET were required for each sub-basin.

2.3.1 Naturalized Streamflow Volume

The streamflow was naturalized at five locations as described in ***Section 2.2***. As described above return flows from irrigation compose a large portion of the naturalized flows and could not be removed from the naturalized streamflow time series at the two downstream locations (POUC2 and GRPC2). Therefore, the mean discharge volumes reported in the water balance below include the unaccounted return flows for these two basins. The mean discharge volumes for the upstream basins represent the “true” naturalized flows.

2.3.2 MAP Volume Estimation

The development of accurate mean areal precipitation (MAP) time series is a critical step in the effective modeling of storm runoff. To create MAP time series for each sub-basin, available historic point precipitation data are transformed into estimates of precipitation averaged over the sub-basin area for each time step. For this project, MAP time series were developed and provided by the MBRFC. MAP time series for the upper basins (EHNC2, NCHC2, and SEAC2) were computed using predefined station weights, beginning with Thiessen weights and adjusting the weights such that the mean seasonal precipitation total equaled long-term mean precipitation totals from the isohyetal maps from the Spatial Climate Analysis Service’s (Oregon State University) Parameter-elevation Regressions on Independent Slopes Model (PRISM). MAP time series for the lower basins (FTDC2, POUC2 and GRPC2) were computed using the Thiessen weights option in MAP without adjusting to match the PRISM total.

As part of the data quality control analysis, annual average MAP values were compared to annual average precipitation over a sub-basin computed from the PRISM maps. Although the mean annual MAP values are over the period of 10/1978 – 9/2003 and the PRISM means were computed for the period of 1/1961 – 12/1991, the comparison can provide insights to potential MAP problems. ***Table 2-4*** provides the direct comparison between the MAP annual averages and the PRISM annual averages. This could explain the discrepancy in the FTDC2 sub-basin. For SEAC2, there is a –6% difference between the Annual MAP and the annual average PRISM precipitation; this corresponds to an annual difference of –1.0 inches. These differences were discussed with the MBRFC, but no adjustments to the MAP time series were made.

Table 2-4. MAP and PRISM comparison results

Basin	Annual MAP (in)	Avg. Annual MAP over sub-basin (in)	Annual PRISM (in)	Difference (MAP – PRISM) (in)	Difference (MAP – PRISM) %
EHNC2LWR	15.1	24.9	25.1	0.2	0.7%
EHNC2UPR	33.0				
NCHC2LWR	17.3	18.2	18.5	0.3	1.9%
NCHC2UPR	29.3				
SEAC2	17.5	17.5	16.5	-1.0	-6%
FTDC2	15.7	15.7	18.4	2.7	15%
POUC2	16.6	16.6	16.4	-0.2	-1.4%
GRPC2	15.7	15.7	14.5	-1.1	-8%

Monthly precipitation characteristics for each sub-basin are plotted in

Figure 2-1. This plot shows the clear difference between lower elevation areas and higher elevation areas and the benefit of subdividing EHNC2 and NCHC2. The monthly precipitation characteristics of the precipitation stations show similar trends.

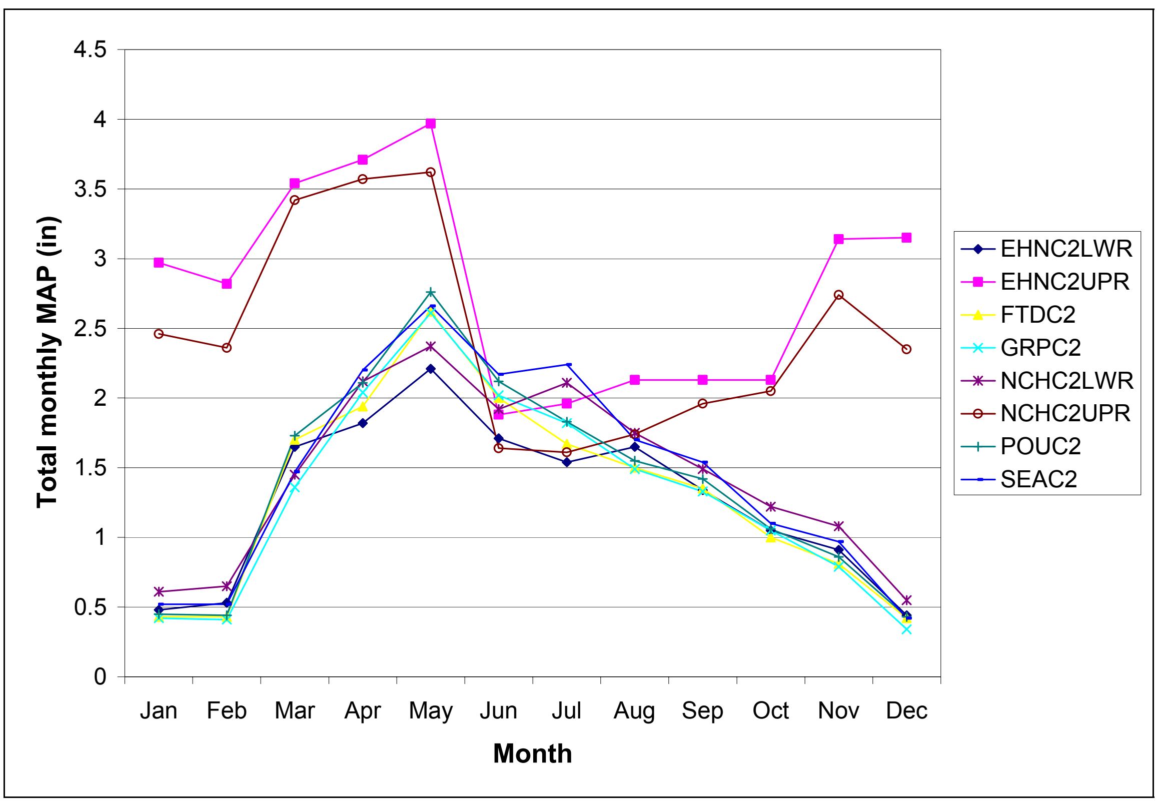

Figure 2-1. Monthly sub-basin MAP characteristics

2.3.3 PET Volume Estimation

The Sacramento model requires daily time series or average monthly estimates of potential evapotranspiration (PET) for input into the model. For the Poudre basin calibrations, the initial PET estimates were computed using the FAO Penman-Montieth method. Refer to FAO Irrigation and Drainage Paper No. 56 (Allen, R.G., et al.) for a description of this method and the associated assumptions.

The following data are required for implementation of this method:

- Monthly Average Maximum and Minimum Daily Temperature at each weather station to be included in the analysis (2 * 12 values per station)

- Temperature Station and Sub-basin Centroid Latitude, Longitude, and Elevation

The temperature information was obtained from an MAT input deck provided by the MBRFC. The deck includes 42 stations. Basin centroids and mean elevations were computed using the basin boundaries and the 30-meter DEM. For the Poudre River project area, it was assumed that the geographic location description of the basins is "Interior" (versus Coastal) and that the average wind speed is 2.0 m/s. For each temperature station, the temperature information was used to compute monthly estimates of PET at the station. The monthly station estimates were then plotted and used to derive monthly linear regression relationships between PET and station elevations. In order to estimate the PET for a sub-basin, the regression relationships were used to adjust the PET estimates at each station to the mean sub-basin elevation. Finally, sub-basin PET estimates were computed from the adjusted station PET estimates using an inverse distance squared weighting scheme with a maximum neighborhood distance of 100 km.

Table 2-5 lists the monthly sub-basin PET estimates computed using the Penman-Montieth method, and ***Figure 2-2*** shows the final adjusted PET estimates. During the hydrologic model calibration process, the PET estimates were reviewed to determine if any adjustments were merited. However, the calibration results indicated that the initial estimates adequately captured the PET characteristics in the sub-basins.

Table 2-5. FAO Penman-Montieth PET estimates in mm/day

Sub-Basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Sum
EHNC2LWR	0.8	1.1	1.7	2.5	3.6	4.7	5.2	4.6	3.4	2.2	1.1	0.8	31.8
EHNC2UPR	0.6	0.9	1.5	2.2	3.2	4.3	4.8	4.2	3.1	1.8	0.9	0.6	28.0
NCHC2LWR	0.8	1.1	1.7	2.6	3.7	4.8	5.4	4.8	3.5	2.2	1.2	0.8	32.6
NCHC2UPR	0.6	0.9	1.4	2.2	3.3	4.1	4.6	4.1	2.9	1.6	0.8	0.6	27.2
SEAC2	0.9	1.2	1.8	2.7	3.8	5.0	5.5	4.9	3.7	2.4	1.3	0.9	34.3
FTDC2	0.9	1.3	1.9	2.8	3.8	4.8	5.4	4.9	3.7	2.4	1.3	0.9	34.1
POUC2	1.0	1.4	2.1	3.1	4.1	5.2	5.7	5.1	3.9	2.6	1.4	1.0	36.6
GRPC2	1.0	1.4	2.1	3.1	4.2	5.3	5.9	5.3	4.0	2.6	1.4	1.0	37.5

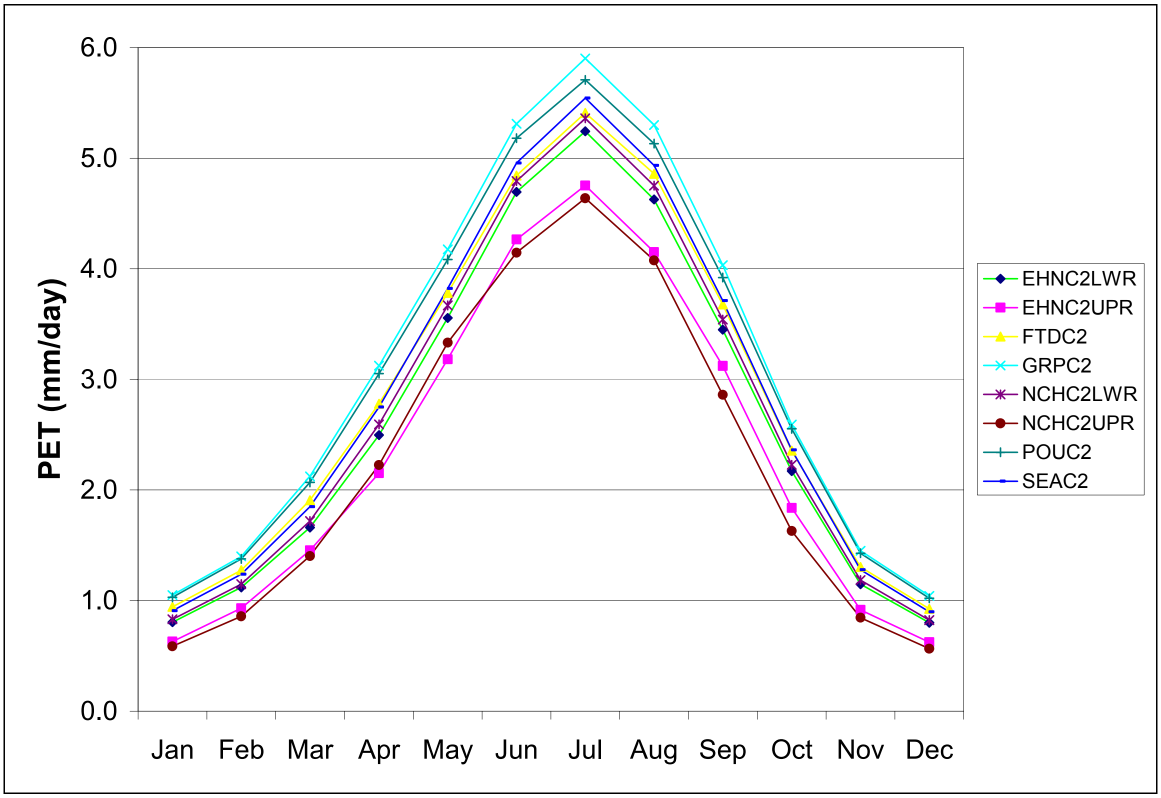

Figure 2-2. FAO Penman-Montieth PET estimates in mm/day

2.3.4 Water Balance Results

A natural water balance analysis was compiled after completing the above quality control steps. The water balance analysis results are shown in ***Table 2-6***. All mean values are computed over the period of 10/1987 – 9/2003. The local QME for POUC2 and GRPC2 includes local contributions plus agricultural return flows and are therefore not entirely natural flows; this will be reflected as a higher QME for these sub-basins than would be attributed solely to local runoff.

Table 2-6. Natural water balance results

Basin ID	Basins	Local Area (mi²)	Total Area (mi²)	PET local (in)	MAP local (in)	QME total (cfsd)	QME local (cfsd)	QME depth (in)	ROC* (QME/MAP)	AET** (MAP-QME) (in)	AET/PET+
NCHC2	N Fk blw Halligan Res	347	347	39	18	26211	26211	2.8	0.16	15.13	0.39
SEAC2	N Fk blw Seaman Res	209	556	41	17	35794	9583	1.7	0.10	15.26	0.37
EHNC2	Poudre blw Elkhorn Crk	399	399	36	25						
FTDC2	Canyon Mouth	79	1034	41	16						
EHNC2+FTDC2	abv Canyon excl N Fk	478	1034	37	23	132513	106301	8.3	0.35	15.05	0.41
POUC2	Fort Collins	163	1197	44	17		11463	2.6	0.16	13.96	0.32
GRPC2	Greeley	655	1853	45	15		54522	3.1	0.20	12.28	0.27

* ROC=Runoff Coefficient=Steamflow Depth/Mean Areal Precipitation

**AET=Actual Evapotranspiration=Mean Areal Precipitation-Streamflow Depth

+Evapotranspiration ratio=AET/PET=Actual Evapotranspiration/Potential Evapotranspiration

The water balance results follow expected trends. The three upper areas (NCHC2, SEAC2, and the combined EHNC2/FTDC2) have very consistent evapotranspiration ratios (AET/PET). The lower sub-basins (POUC2 and GRPC2) have lower AET/PET ratios, but this can be attributed to the groundwater return flows that were not removed from the naturalized flow time series, which in turn cause the AET values for these basins to be lower than the other sub-basins. The runoff coefficient (ROC) from the combined EHNC2 and FTDC2 basins is significantly higher due to the large high elevation area in EHNC2 that produces higher runoff. The ROC for NCHC2 is higher than that of SEAC2, as expected due to the high elevation zone in NCHC2. Again, the ROC values for POUC2 and GRPC2 are high due to the unaccounted for return flows.

The water balance results indicate the MAP computations, PET estimations, and flow naturalization are all reasonably consistent.

3.0 APPROACH 1 DEVELOPMENT—NATURAL FLOW CALIBRATION

In the first modeling approach, hydrologic models were calibrated to represent the naturalized flows that would be present in the Poudre River in the absence of regulation. The streamflow at NCHC2, SEAC2, and FTDC2 was naturalized in previous steps and used in this approach as the observed streamflow for calibration of the models. The purpose of completing this approach was to provide a baseline for comparison for determining the benefits of regulation modeling and to determine hydrologic model parameters for use in the second and third modeling approaches. The hydrologic models included the unit hydrograph model (UNIT-HG), Lag and K routing model (LAG-K), Hydro-17 Snow Accumulation model (SNOW-17), and Sacramento Soil Moisture Accounting model (SAC-SMA).

3.1 Unit Hydrographs

Unit hydrographs were developed using the Integrated Hydrologic Automated Basin Boundary System (IHABBS) and provided by the MBRFC for all six of the sub-basins in the Poudre. Although the highest sub-basins are sub-divided into upper and lower elevation zones, the output from the Sacramento models from each zone is weighted by area and passed through a single unit hydrograph representing the entire sub-basin rather than passing the runoff from each zone through an individual unit hydrograph. The areas of the sub-basins were used to check the ordinates of the unit hydrographs, and in some cases, the initial ordinates were adjusted slightly to represent the true sub-basin area. The unit hydrographs were reviewed during the calibration process and no clear adjustments were merited. The unit hydrographs are shown in

Figure 3-1 below.

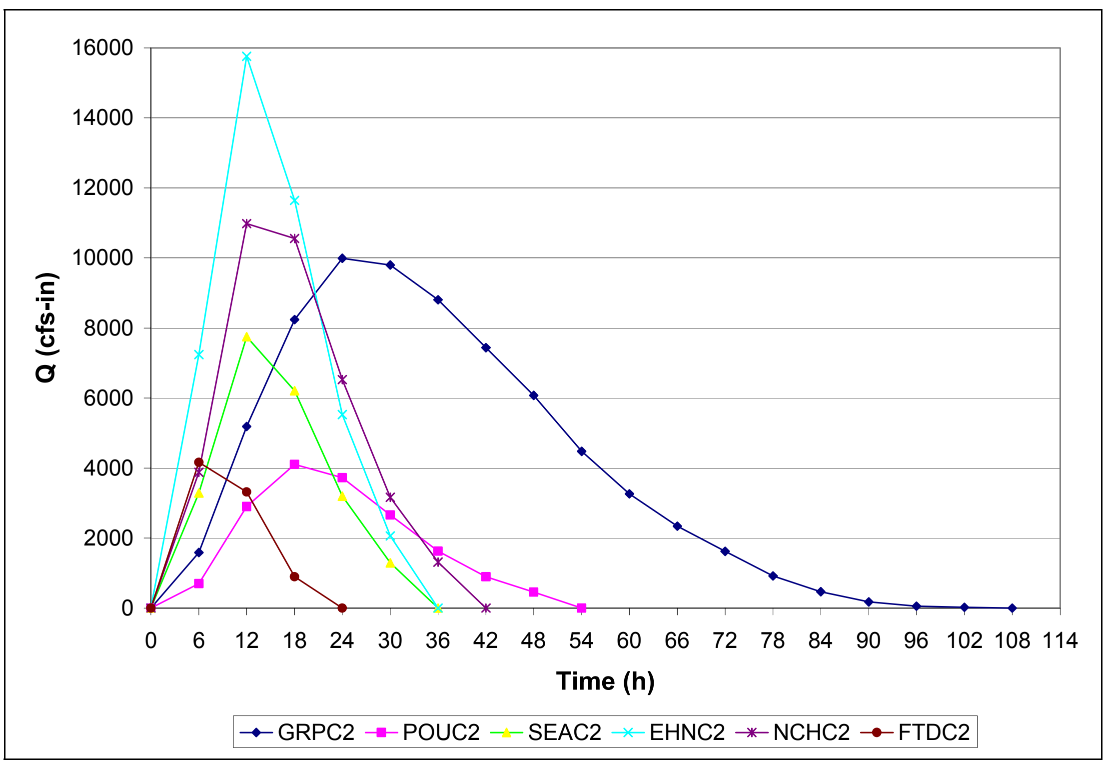

Figure 3-1. Unit hydrographs adjusted to the correct area for the sub-basins of the Poudre

3.2 Lag/K Routing Parameter Estimation

The Lag/K channel routing method was used in the Poudre to route upstream discharge to downstream forecast points. This method includes a translation component (Lag) and an attenuation component (K) to account for the movement of a flood wave through a channel reach. In an ideal situation, instantaneous discharge data at the upstream and downstream ends of a reach would be used to calibrate the Lag and K parameters. Instantaneous discharge data were unavailable in these sub-basins and routing parameters were estimated using relationships developed from stage-discharge measurements at gaging stations and GIS-derived slope and stream length data. Routing parameters were computed to route flow between forecast points and route the aggregated regulation effects downstream to forecast points.

Stage-discharge measurements were downloaded from the USGS web site for four gages on the Poudre (Two sites on the North Fork of the Poudre, the Lincoln Street (POUC2) gage, and the Boxelder gage located just downstream of the Lincoln Street gage). The measured velocity and discharge data were plotted for each site and compared between sites. All of the sites showed similar characteristics of increasing velocity with discharge. The Q-V relationships for the Fort Collins gage are shown in ***Figure 3-2*** below. Because of the clear variation of average velocity with discharge, a variable lag-discharge relationship was implemented. Four different velocity-discharge points were specified for each reach (at Q = 10, 200, 1000, and 3000 cfs).

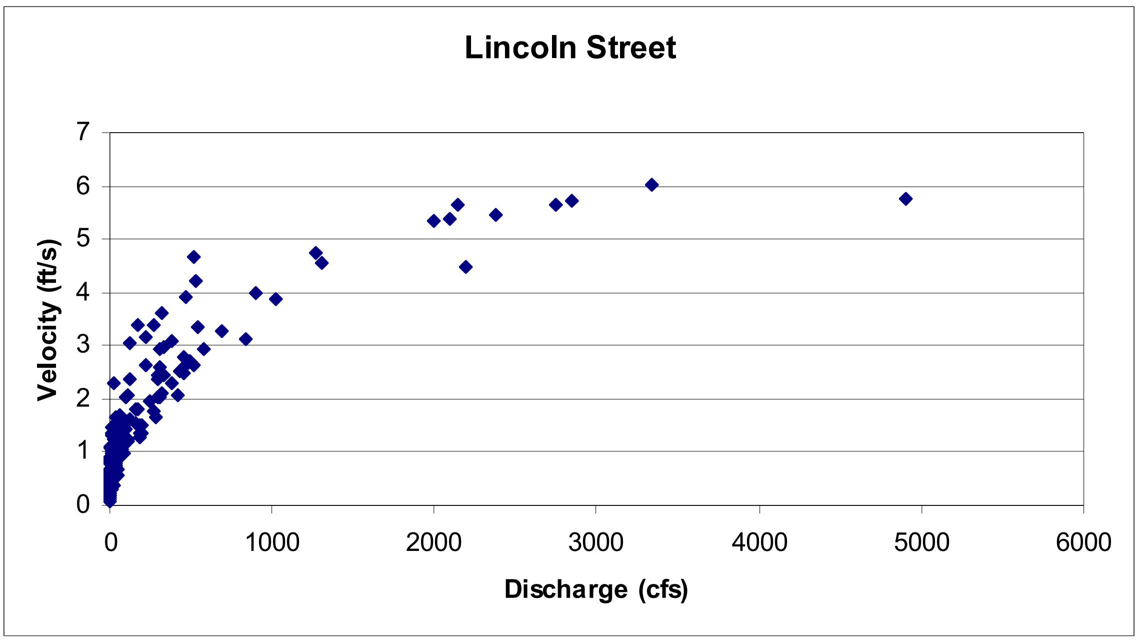

Figure 3-2. Velocity versus discharge based on USGS measurements

Manning's equation relates average velocity to hydraulic radius, channel roughness, and slope. Assuming that the hydraulic radius and channel roughness is relatively consistent from reach to reach, Manning's equation can be used to determine the effects of slope on stream velocity using the following:

$$V = kS^{1/2} \tag{1}$$

$$k = \frac{\phi R^{2/3}}{n} \tag{2}$$

where V is velocity, S is slope, ϕ =1.0 for Metric or 1.486 for English units, R is hydraulic radius, and n is Manning's roughness coefficient.

At the Lincoln Street gage, stage observations were used to estimate the hydraulic radius, R (assuming R = stage) for each discharge of interest. The channel slope was estimated in GIS over a 5 km length of stream extending from above to below the gage. The Manning's roughness coefficient was assumed constant for all discharges and was adjusted to produce a velocity-discharge relationship reasonably consistent with the above observed velocity-discharge relationship (

Figure 3-3). A separate value of k was computed for each discharge level, and used in the remaining reaches in Equation (1) to compute channel velocities for a given discharge level.

Reach slopes were estimated using the National Hydrology Dataset (NHD) streamflow coverage, USGS streamflow station elevations, and the NED 30-meter DEM. The computed k values and reach slopes were used to estimate average velocities at four discharges for the reaches where routing parameters were estimated. The resulting relationship between velocity and slope is plotted in ***Figure 3-4***.

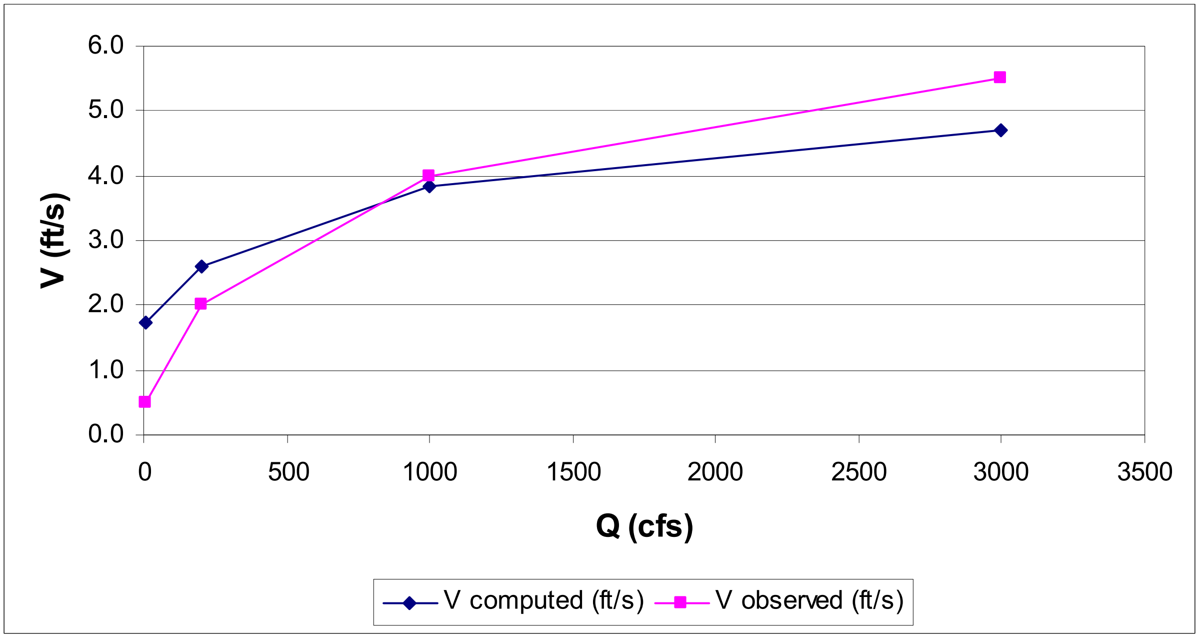

Figure 3-3. Observed and computed velocity-discharge relationships

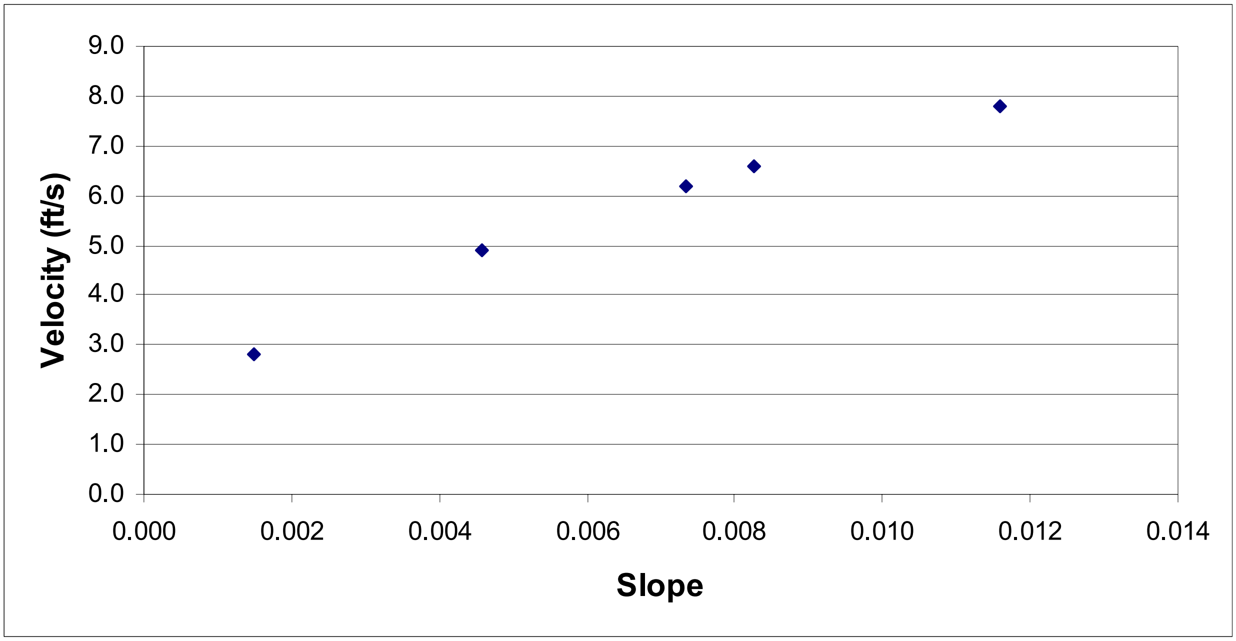

Figure 3-4. Variation in velocity due to slope for different reaches at Q=1000 cfs

The reach lengths were then used to estimate average reach travel times and to approximate the Lag parameter. It was assumed that the flood wave velocity was 1.5 times the channel velocity in order to approximate the lag time parameter (based on Chezy's equation, assuming kinematic waves and a wide, rectangular channel). If the lag time was computed to be less than 2 hours, the Lag parameter was set equal to zero.

The attenuation parameter, K, is a function of the storage along a reach. Since no information was available for estimating K, the value of K was set equal to half of the lag time. For reaches with lag times less than 6 hours, K was set equal to zero.

The computed routing parameters were compared to the Tatum routing parameters currently in place for the Poudre. The routing estimates are reasonably consistent between the two methods. The simulated routed flows were compared with downstream observations during the naturalized flow calibration process. As no short-interval data were available and comparisons were being made with naturalized flows, there were no clear indications that adjustments to the Lag-K estimates were needed.

In the second modeling approach, regulations were lumped together as described in ***Section 2.2.2*** and their effects were routed downstream. Routing parameters for the regulations were derived using the same methods described above. Final routing parameters are shown in ***Table 3-1*** below for routing between forecast points and routing for these grouped regulations.

Table 3-1. Lag and K parameters for reaches and regulations

	Q=10 cfs		Q=200 cfs		Q=1000 cfs		Q=3000 cfs	
Reach	**Lag (h)**	**K (h)**	**Lag (h)**	**K (h)**	**Lag (h)**	**K (h)**	**Lag (h)**	**K (h)**
NCHC2-SEAC2	6.9	3.4	4.5	0	3.1	0	2.5	0
SEAC2-FTDC2	0	0	0	0	0	0	0	0
EHNC2-FTDC2	5.6	0	3.7	0	2.5	0	2.1	0
FTDC2-POUC2	5.1	0	3.4	0	2.3	0	0	0
POUC2-GRPC2	32.4	16.2	21.4	10.7	14.5	7.3	11.8	5.9
Regulation routing	**Lag (h)**	**K (h)**	**Lag (h)**	**K (h)**	**Lag (h)**	**K (h)**	**Lag (h)**	**K (h)**
Worster to NCHC2	2.5	0	0	0	0	0	0	0
N Poudre Canal to SEAC2	4.9	0	3.3	0	2.2	0	0	0
Upper reservoirs to EHNC2	7.7	3.9	5.1	0	3.5	0	2.8	0
Middle Greeley diversions to GRPC2	22.3	11.2	14.7	7.4	10.0	5.0	8.2	4.1

3.3 SNOW-17 and SAC-SMA Model Calibration

The streamflow was naturalized at five locations along the Poudre River. At three of the five locations (NCHC2, SEAC2, and FTDC2), there are not significant agricultural return flows upstream of the outlet point. The naturalized streamflow time series provided a means to calibrate the SNOW-17 and SAC-SMA model parameters. In the downstream sub-basins (POUC2 and GRPC2), the influence of agricultural return flows limited the amount of parameter estimation that could be done. However, the local area contribution due to runoff is relatively small for these basins, and therefore regional parameter sets provided a reasonable estimate of the local area runoff.

The calibration period for all of the sub-basins was limited by data availability. The calibration period was set to 10/1987 – 9/2003 for all the sub-basins.

Some parameters were initially estimated using GIS tools. The Effective Forest Cover (EFC) and Percent Impervious (PCTIM) parameters were estimated using the 30-meter National Land Cover Dataset (NLCD) available from the USGS (http://landcover.usgs.gov). Other initial parameters were set based on the previous segment definitions of the MBRFC, guidelines from the NWSRFS documentation, and previous RTi experience in similar settings.

For the upstream sub-basins, the evaluation of SNOW-17 and SAC-SMA model input parameters is based on the visual closeness of observed and simulated hydrographs as well as overall simulation error statistics. For this project, the STAT-QME operation was used to compute a variety of summary statistics useful for evaluation purposes. Steps were taken to ensure the quality of the calibrations and consistency of the resulting parameters. After initial calibration of the Poudre River sub-basins, the calibrations were reviewed in detail by a senior engineer.

The final SNOW-17 and SAC-SMA parameters are shown in ***Table 3-2*** and ***Table 3-3***, respectively. Local and total simulation statistics are listed in ***Table 3-4*** and ***Table 3-5***. The annual bias statistics were computed separately from STAT-QME to account for negative flows in the computations. High flow bias statistics depict the values from the highest flow bracket of the STAT-QME output that contain at least 50 data points.

Basin-specific calibration notes are included in the subsequent sections.

Table 3-2. Calibrated SNOW-17 model parameters

Sub-Basin	PXADJ	SCF	MFMAX	MFMIN	NMF	UADJ	SI	DAYGM	MBASE	PXTEMP	PLWHC	TIPM	AESC
NCHC2	0.9	1.05	0.6	0.2	0.15	0.05/0.07	999	0.3	0.0	1.0	0.03	0.2	24,37,44,50,53,57,60,66,78 / 24,37,46,55,62,68,72,77,87
SEAC2	1.0	1.30	0.6	0.2	0.15	0.07	999	0.3	0.0	1.0	0.03	0.2	24,37,46,55,62,68,72,77,87
EHNC2	1.0	1.23	0.7/0.5	0.2	0.15	0.05	450/999	0.3	0.0	1.0	0.03	0.2	22,28,33,40,46,55,64,74,84 / 40,54,63,71,78,82,87,91,95
FTDC2	1.0	1.23	0.5	0.2	0.15	0.05	999	0.3	0.0	1.0	0.03	0.2	40,54,63,71,78,82,87,91,95
POUC2	1.0	1.10	0.6	0.2	0.15	0.07	999	0.3	0.0	1.0	0.03	0.2	40,54,63,71,78,82,87,91,95
GRPC2	1.0	1.10	0.6	0.2	0.15	0.07	999	0.3	0.0	1.0	0.03	0.2	40,54,63,71,78,82,87,91,95

Table 3-3. Calibrated SAC-SMA model parameters

Sub-Basin	UZTWM	UZFWM	UZK	PCTIM	ADIMP	RIVA	ZPERC	REXP	LZTWM	LZFSM	LZFPM	LZSK	LZPK	PFREE	EFC
NCHC2	25/20	30	0.30	0.004/0.006	0.005	0.010	85	1.90	400/100	50	80	0.13	0.003	0.25	0.835/0.380
SEAC2	20	32	0.35	0.011	0.005	0.000	85	1.90	75	40	65	0.08	0.005	0.25	0.291
EHNC2	20	30	0.30	0.007/0.014	0.005	0.000	85/150	1.90	100	70	80	0.05	0.003	0.25	0.707/0.660
FTDC2	20	30	0.30	0.01	0.005	0.000	150	1.90	100	70	80	0.05	0.003	0.25	0.543
POUC2	25	30	0.30	0.086	0.005	0.000	150	1.90	150	50	80	0.08	0.003	0.25	0.116
GRPC2	25	30	0.30	0.07	0.005	0.000	150	1.90	150	50	80	0.08	0.003	0.25	0.007

Table 3-4. Local natural flow calibration statistics

Sub-Basin	Simulated Local Flow (cmsd)	Annual % Bias	C.Coeff. Daily Flows	Daily RMS Error (cmsd)	Adjusted Local Nat Flow (cmsd)	*(Daily RMS Error) / (Adj Loc Nat Flow)*	OBS=A+B*SIM (A, B)	High Flow Bias %
NCHC2	2.02	-0.64	0.676	2.65	2.03	1.30	0.58, 0.72	-33.6
SEAC2	0.74	0.55	0.837	1.18	0.73	1.61	0.08, 0.93	-40.1
EHNC2+FTDC2	7.41	-1.16	0.955	4.02	7.50	0.54	0.40, 0.96	-10.3

Table 3-5. Total flow calibration statistics

Sub-Basin	Simulated Total Flow (cmsd)	Annual % Bias	C.Coeff. Daily Flows	Daily RMS Error (cmsd)	Adjusted Total Nat Flow (cmsd)	*(Daily RMS Error) / (Adj Tot Nat Flow)*	OBS=A+B*SIM (A, B)	High Flow Bias %
NCHC2								
SEAC2	2.80	0.14	0.969	1.22	2.80	0.44	0.01, 1.00	3.2
EHNC2+FTDC2	10.19	-0.85	0.971	4.02	10.27	0.39	0.24, 0.99	-5.6

3.3.1 North Fork of the Poudre below Halligan Reservoir (NCHC2)

The NCHC2 sub-basin is sub-divided into two elevation zones with 8% of the basin above 9500 ft and 92% below 9500 ft. Although the upper elevation zone is a relatively small percentage of the entire sub-basin, this zone receives significantly more precipitation than the lower elevation zone. The precipitation gage coverage for the sub-basin is sparse, with a single gage located at the top of the sub-basin and another to the East of the sub-basin (see the coverage map in ***Figure 1-2***). Streamflow has been recorded at the Halligan USGS gage since March 1998, and at the downstream Livermore gage between Halligan and Seaman reservoirs beginning in October 1986. Therefore, as described in the data collection (***Section 2.2.1***), the streamflow at the NCHC2 outlet is based on regressions with the downstream Livermore gage after adding back in an intermediate diversion before 3/1998.

All of the above factors contributed to difficulties in accurately modeling the runoff response from this sub-basin. After attempting to adjust model parameters to capture the volume of runoff generated from this sub-basin, a PXADJ of 0.9 was applied to both elevation zones to reduce the runoff from the sub-basin. The need for this factor could be attributed first to the lack of gage coverage over the basin. In addition, the precipitation for the lower elevation zone is estimated in part using a high elevation precipitation gage, which may have resulted in an overestimation of the precipitation. Finally, the elevation sub-division of this sub-basin created a very small upper elevation zone. If the elevation break were at a slightly lower elevation, it is possible that the runoff could be more accurately captured. A review of MAP station weights should be completed to allow PXADJ to be changed to 1.0.

During the modeling effort, it was clear that there was a different model response in the upper and lower elevation zones. This is reflected primarily in differences in LZTWM in the upper and lower elevation Sacramento models.

3.3.2 North Fork of the Poudre below Seaman Reservoir (SEAC2)

During the calibration of SEAC2, the MAP was decreased in July 1997. In this month, a large, localized precipitation event occurred over the city of Fort Collins causing flash flooding in the city. A precipitation gage located in the city receives weight for this basin, and it appeared the precipitation was significantly overestimated for this event in the SEAC2 sub-basin as a result of the nature of the storm.

The local SEAC2 area contributes a relatively small fraction of runoff to the total streamflow at the outlet of the basin. The calibration effort therefore focused on the total flows. The SNOW-17 model parameters are the same as the lower elevation zone of NCHC2, with the exception of the snow correction factor (SCF). The calibration focused primarily on adjusting the SAC-SMA model parameters.

3.3.3 Poudre River at the Canyon Mouth (combined EHNC2 and FTDC2)

No streamflow records were available over the calibration period for the EHNC2 sub-basin. Therefore, this sub-basin was calibrated with the downstream FTDC2 sub-basin.

The local area contribution of the combined EHNC2 and FTDC2 sub-basins is greater than the flows generated by the North Fork (NCHC2 and SEAC2). The natural runoff response is snowmelt-dominated, with the majority of the Canyon Mouth flows originating in the upper elevation zone of EHNC2. The upper elevation zone comprises 55% of the EHNC2 sub-basin. However, roughly 95% of the local area simulated discharge can be attributed to the upper elevation area. The large local area contribution and clear snowmelt hydrograph permitted tuning of the snow model parameters to a greater degree than was possible in the North Fork. The results of the Canyon Mouth calibration were used to adjust the snow model parameters in the North Fork sub-basins.

3.3.4 Poudre R. at Lincoln Street, Fort Collins (POUC2) and at Greeley (GRPC2)

The flow naturalization process for the POUC2 and GRPC2 sub-basins yielded local area naturalized flows. However, as indicated in ***Section 2.2.3***, return flows could not be accounted for in the naturalization process and therefore compose a significant portion of the "naturalized" local area flows for these sub-basins. As a result, a regional parameter set was developed for the SNOW-17 and SAC-SMA models based on the results of the upstream calibrations (NCHC2, SEAC2, and the combined EHNC2/FTDC2 sub-basins). The local area contributions from POUC2 and GRPC2 were reviewed during Approaches 2 and 3, yet the impact of these local areas is relatively small compared to both upstream flows and the effects of regulation in the sub-basins, and no adjustments were made to the model parameters.

4.0 APPROACH 2 DEVELOPMENT—USING HISTORIC TIME SERIES OF REGULATION

In the second modeling approach, the effects of regulation were incorporated into the forecasting system using observed time series of regulations developed during previous steps. The hydrologic model parameters developed in the first modeling approach were applied in Approach 2. Thus, during the calibration phase, there was little work involved in Approach 2 beyond identifying the appropriate time series and operations used to manipulate the time series. In the downstream sub-basins, however, return flow time series had to be created since no observations of agricultural return flows are available.

In the real-time forecasting system, this modeling option could be used to provide a means of producing long-range streamflow forecasts using historic patterns of regulation. The initial implementation effort is relatively small compared to a full modeling approach of regulations. However, no information concerning current model states would be used by the system for specifying regulations, and information concerning current or future regulations would be unavailable within the system. The implications of the various modeling approaches are discussed in ***Section 8.1***.

4.1 Return Flow Development

Data were collected for all observable regulations in each sub-basin as described in ***Section 2.2***. However, no observations of agricultural return flows were available because they are non-point source flows. In the upper sub-basins above FTDC2, there is little irrigation and thus negligible return flows. In the lower sub-basins (POUC2 and GRPC2), significant irrigation occurs and the agricultural returns compose a large percentage of the local area runoff. The "naturalized" flows were used to quantify the agricultural return flows and create a time series of return flows for use in this second modeling approach.

In order to quantify the return flows for the POUC2 and GRPC2 sub-basins, two time series were compared in each sub-basin. 1) Local Naturalized flows computed as described in ***Section 2.2.3*** (local area runoff with all regulation except agricultural return flows removed) and 2) Simulated local area natural runoff using SNOW-17 and SAC-SMA models with regional hydrologic model parameters developed as described in ***Section 3.3.4*** (simulated local area runoff with no regulation effects). Theoretically, the difference between these two time series would be the return flows. However, all errors in the two time series (both simulated and observed) are also encompassed in this difference, which therefore contains substantial noise.

The two daily time series described above were summed on a monthly basis to produce monthly time series to minimize the noise. The difference between the monthly time series was computed and plotted to view the monthly variation in the theoretical return flows. However, there still were many periods with negative values, or periods with unreasonably large values. Therefore, the annual return flow volume was computed for each sub-basin in the same manner.

The sum of the annual return flows from the two sub-basins appeared to follow a smoother annual trend than the annual return flows in one or the other sub-basin. The annual trend followed an inverse relationship with the mean annual MAP over the sub-basins, which would make sense if heavier irrigation occurs in drier periods, causing higher return flows. The fraction of mean annual return flows in each sub-basin (13% in POUC2 and 87% in GRPC2) was used to produce an annual return flow time series for each sub-basin (***Figure 4-1***).

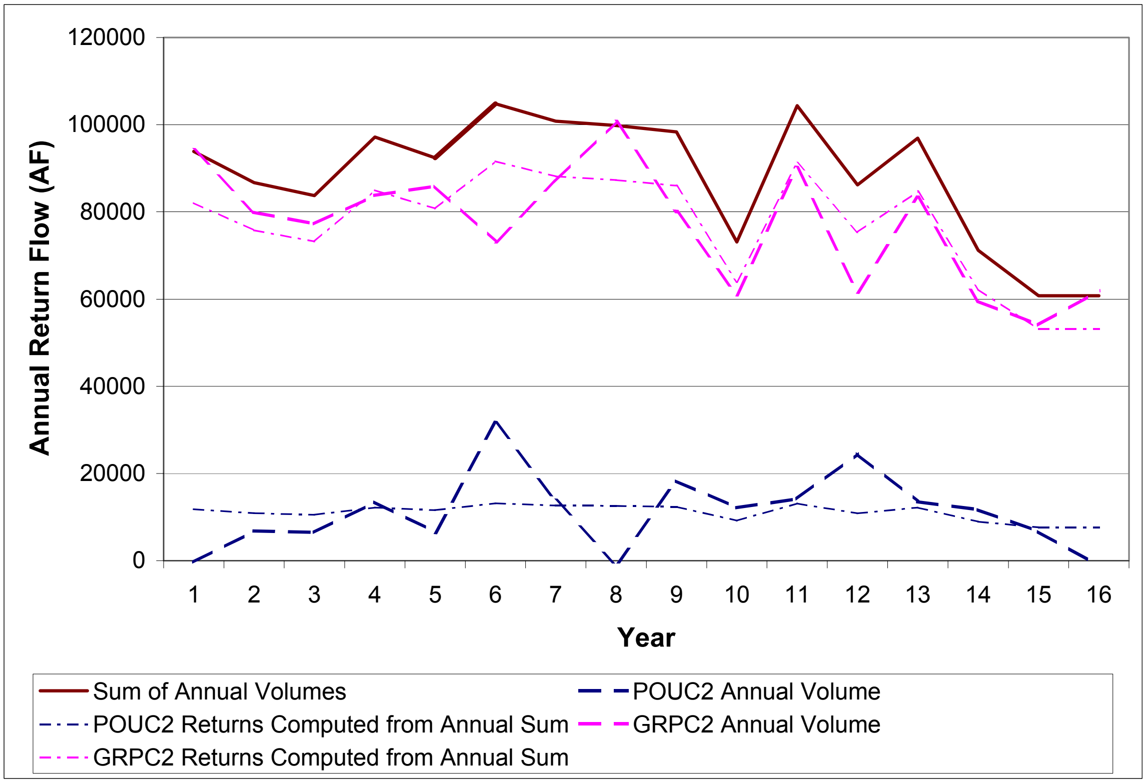

Figure 4-1. Annual return flow patterns in POUC2 and GRPC2

The monthly return flow time series were then plotted for each year, and an average monthly distribution of return flows was manually fit to the data for each sub-basin. The average monthly distribution follows expected trends with a gradual ramping up of return flows beginning in late spring and a peak in return flows in late summer (***Figure 4-2*** and ***Figure 4-3***). The monthly distribution for each sub-basin was used to distribute the annual return flow volumes to a monthly time series. Finally, the monthly return flows were linearly interpolated to produce daily return flow time series for each sub-basin.

These daily time series were used as an additional observed regulation input for the POUC2 and GRPC2 sub-basins in modeling Approach 2.

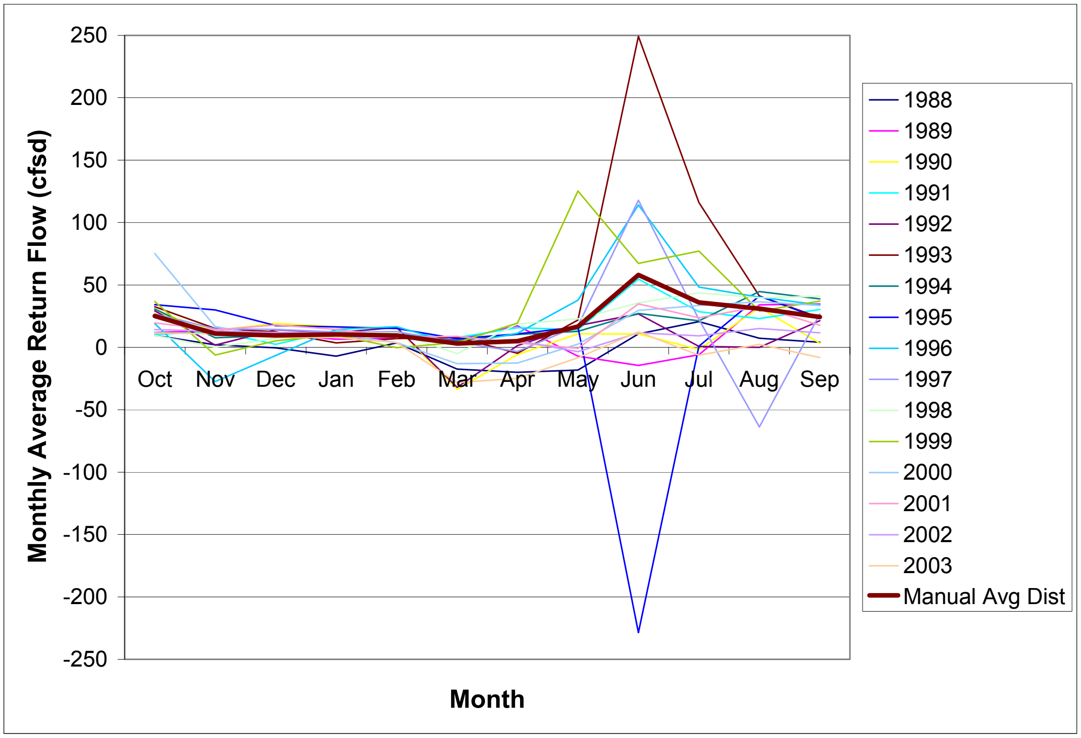

Figure 4-2. Monthly return flow distribution in POUC2

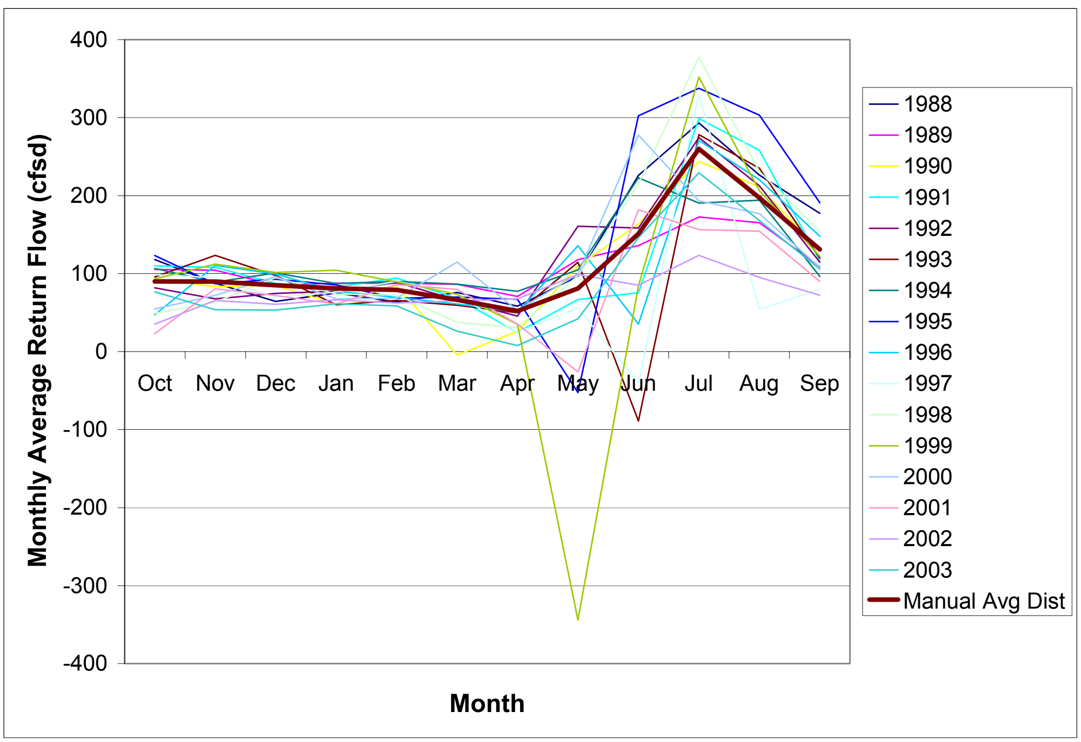

Figure 4-3. Monthly return flow distribution in GRPC2

4.2 Sub-basin Configurations

The sub-basin configurations for Approach 2 were fairly straightforward. ***Section 2.2.2*** describes the creation of the net regulation time series, representing all the observable regulation occurring in each sub-basin. The above section described the generation of return flow time series for use as observations in the lower sub-basins. Calibration decks were created that contained the same hydrologic models and model parameters developed in modeling Approach 1, in addition to operations that add the net regulation time series and the return flow time series to generate total flow time series at each sub-basin outlet. No calibration work could be done in this approach beyond verifying the return flow approximations.

5.0 APPROACH 3 DEVELOPMENT—MODELING OF REGULATIONS

The third and final modeling approach involved developing a complete representation of all basin regulations using a variety of NWSRFS models and operations in conjunction with the hydrologic models to generate total streamflow forecasts at each sub-basin outlet. This approach built on the work of the previous approaches, using hydrologic model parameters from Approach 1 and intermediate regulation time series generated for Approach 2 as observed time series to calibrate specific regulation effects.

5.1 General Calibration Strategy

The model development and calibration followed a general sequence, although in practice the development and calibration was an iterative process. First, all appropriate time series were generated and aggregated as described in the data analysis section. The hydrologic models were calibrated as described using natural flow time series. Additional supplemental information, such as basin-wide crop demand, was modeled based on typical relationships and verified using independent studies. Relationships between regulations and a variety of hydrologic variables were investigated, and those regulations with clear relationships were modeled outside of RES-J by calibrating to appropriate aggregated observed regulation time series. Information concerning the various reservoirs in the basin was compiled to set up the basic RES-J model structure. During the initial RES-J calibration, as many variables as possible were represented using observed time series to isolate specific regulation responses. For instance, the natural flow time series were used in the upper sub-basins rather than the simulated flows to represent the local runoff response, and observed imports to the EHNC2 and NCHC2 sub-basins were used instead of simulated imports. This allowed the RES-J models to be calibrated to capture the regulation effects rather than the combined regulation effects plus other model errors. Finally, after calibrating the RES-J model using many observed time series, the observed time series were replaced with model simulations and the total simulation quality was reviewed.

The general approach of separately calibrating the hydrologic models and the regulations was relatively efficient and provided a reasonable means of isolating and calibrating different modeling components.

5.2 Overview of Model Structure

The third modeling approach included three major parts:

- Pre-processing - local flow time series, consumptive use demands, trans-basin imports and some diversions and return flows are generated in preparation for modeling the regulation interactions in the basin using RES-J.

- RES-J modeling – physical and conceptual reservoirs are modeled, including their interactions and dependencies upon one another.

- Post-processing and forecast development – reservoir model results are combined with additional operations to compute total simulated flow at forecast points.

Each of these divisions is described in detail in the following sections. The physical processes being modeled are noted throughout the descriptions. The various conceptual components of the approach 3 modeling are shown in the following diagram (***Figure 5-1***).

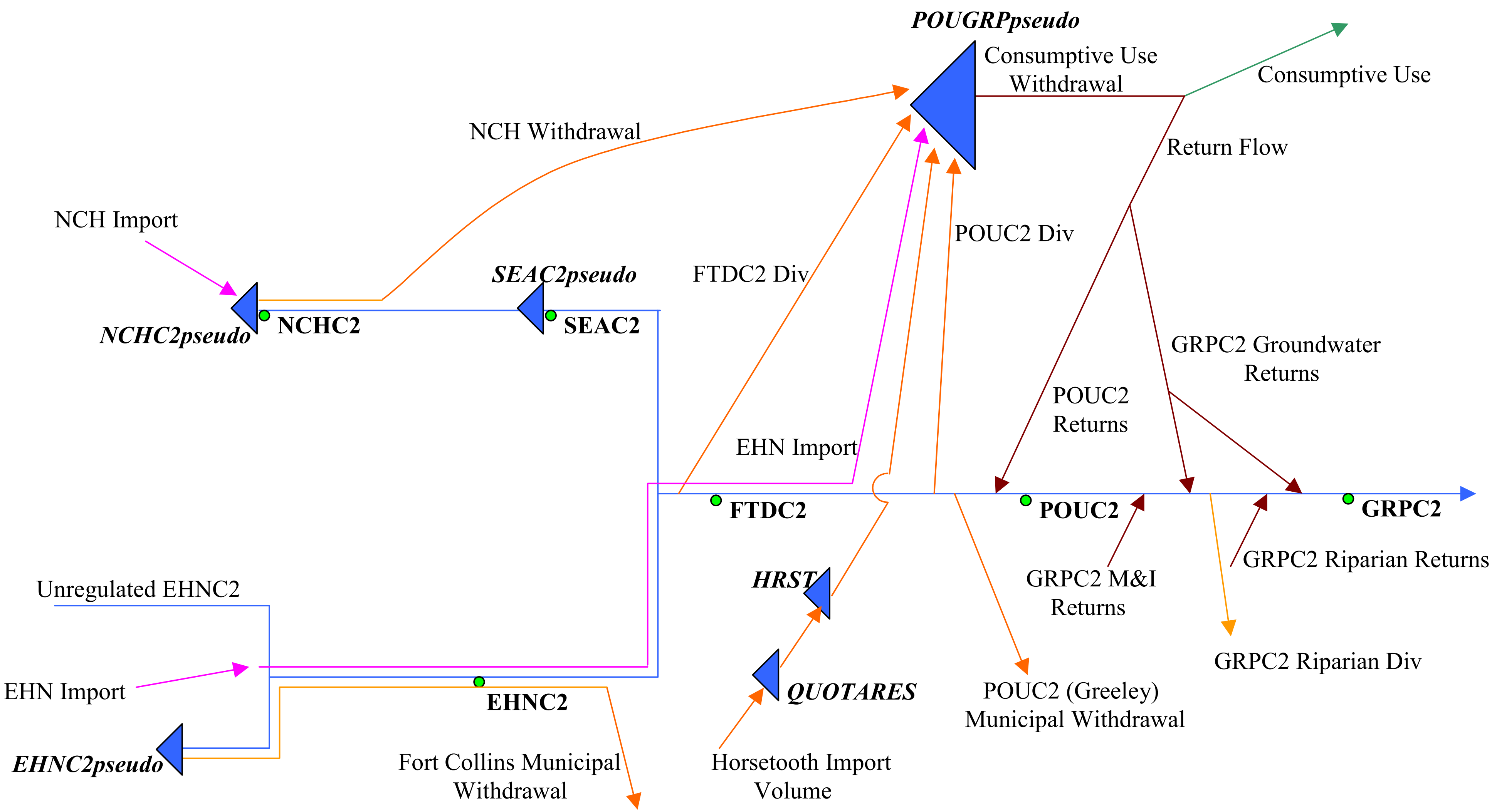

Figure 5-1. Modeling overview diagram for Approach 3

5.3 Pre-Calculated Runoff and Regulations

The first step of modeling Approach 3 involved computing multiple components of runoff and regulation that are subsequently used by the RES-J segment.

5.3.1 Local Area Runoff

The local area runoff in each sub-basin is computed using the same hydrologic models and parameters developed in Approach 1. The output from each local sub-basin was used as input into the RES-J segment and for estimation of other regulations.

5.3.2 EHNC2 Trans-basin Imports

The EHNC2 trans-basin imports were calibrated by comparing the local EHNC2 simulated hydrologic runoff with the aggregated trans-basin import time series. The imports were correlated to the natural runoff, subject to an upper limit. The imports are generated using two CHANLOSS operations. In the first, the variable percentage option is used to take a varying percentage of the EHNC2 natural runoff each month. The second is used to set an upper limit on the amount of flow that may be imported into the basin at different times of the year.

5.3.3 NCHC2 Trans-basin Imports

The NCHC2 trans-basin imports are generated using a single CHANLOSS operation. The NCHC2 imports were not well correlated to the natural runoff as they were in the EHNC2 sub-basin, and are of a much smaller magnitude. Therefore, the same methods described above were not used, and instead a fixed monthly flow was implemented using a CHANLOSS operation.

5.3.4 FTDC2 Diversion

The FTDC2 diversion represents the aggregate diversion upstream of the Canyon mouth stream gage. The diversions generally are extracted from the unregulated portion of the flow at FTDC2 and sent to a group of plains reservoirs for irrigation uses, with the exception of the Fort Collins municipal water treatment plant (WTP) diversion, which is supplied by the reservoirs in the EHNC2 sub-basin. The WTP diversion is modeled in the RES-J model.

In order to model this diversion, the unregulated flow was first approximated as 65% of the EHNC2 sub-basin natural runoff and 100% of the FTDC2 sub-basin natural runoff. This simulated, unregulated flow was then correlated with the observed diversions from the FTDC2 basin (excluding the WTP diversion). The diversion was modeled in the same fashion as the EHNC2 trans-basin imports, using CHANLOSS with a variable monthly percentage of the unregulated flow. This was then subjected to an upper limit defined using a separate CHANLOSS operation.

5.3.5 POUC2 Regulations

Multiple regulations occurring in the POUC2 sub-basin are modeled outside of RES-J. These include the consumptive use demand for irrigation on the plains reservoirs, the trans-basin imports through Horsetooth Reservoir, diversions for the Greeley water treatment facility, and additional diversions from the Poudre to the plains reservoirs between FTDC2 and POUC2.

5.3.5.1 Consumptive Use Demand on Plains Reservoirs

In the Poudre basin, a group of small reservoirs in the POUC2 and GRPC2 sub-basins store and release water for irrigation purposes. Major diversions along the Poudre send water to these reservoirs. The water use from the reservoirs is driven primarily by water rights, yet these water rights and demand for water are actually driven by the consumptive use needs of crops in the basin. In the regulation modeling, the crop demand was used to drive the releases from a synthetic reservoir representing the sum of the small irrigation reservoirs.

The NWSRFS consumptive use model was used to compute the crop demand. The consumptive use model is normally implemented to compute actual diversions from a natural stream based on agricultural demand; however, in this case only the crop demand computations of the model were utilized. A synthetic source was created so that the model would never be supply limited.

GIS tools were used to determine the total area irrigated by the canals originating from the Poudre River. Additionally, crop type data for the Poudre basins were collected. For each crop type, estimates of monthly consumptive use empirical coefficients and growing season lengths were available from the FAO Publication 56. This information was used to derive monthly empirical coefficients for use in the consumptive use model. The MAT time series provided by the MBRFC were used for the temperature input into the model, where the POUC2 and GRPC2 MAT time series were weighted based on area.

The NWSRFS consumptive use model does not account for rainfall that satisfies the demand of the crops. Therefore, the computed demand was adjusted by the MAP by routing the MAP time series through a unit hydrograph of constant duration over a two day period, assuming the water would be available for longer than the initial time step in which it falls. This MAP volume was then subtracted from the crop demand to generate an adjusted crop demand time series.

In a separate point flow analysis conducted by RTi, the monthly distribution of crop demand for the entire Poudre basin was determined. This study was compared with the results of the above modeling. The results indicated the computed consumptive use was underestimated and the timing was skewed to later in the season. Therefore, the monthly empirical crop coefficients were manually adjusted to yield a crop demand with similar volume and timing as determined by the point flow analysis.

5.3.5.2 Horsetooth Trans-basin Imports

Every year, on April 15, the Northern Colorado Water Conservancy District (NCWCD) sets a quota for their water users that determines the amount of water transferred from Lake Granby in the Colorado River basin through the Colorado-Big Thompson (CBT) system to the Poudre River basin. The quota is assigned as a percentage of a full quota, which for agricultural uses translates into approximately 100,000 acre-feet. The imported water is used by both municipal and agricultural users, although the municipal uses never reach the Poudre River. The quota is set by the NCWCD based on the potential yield of the Poudre system, assigning a higher quota when the expected water availability is low. The potential water availability is determined from snow pack measurements, reservoir contents, and climatological forecasts.

The actual volume of water delivered in a given year varies from the quota amount due to a number of factors. NCWCD has a carryover program that allows users to withhold up to 20% of their respective shares of water in a given year and use that water the following year. The program promotes water conservation and allows NCWCD to utilize and store water originating within the Poudre basin before using CBT water. If water is withheld for carryover, it has to be used by July 15 of the following year. At that point, any remaining carryover is lost to the user and goes towards fulfilling the total quota volume for the current year. The variability of the total volume of water delivered for agricultural uses for a given annual quota is shown in ***Figure 5-2*** for the period 1987 – 2002. The volumes are summed from June through May to attempt to remove some of the variability due to the carryover program.

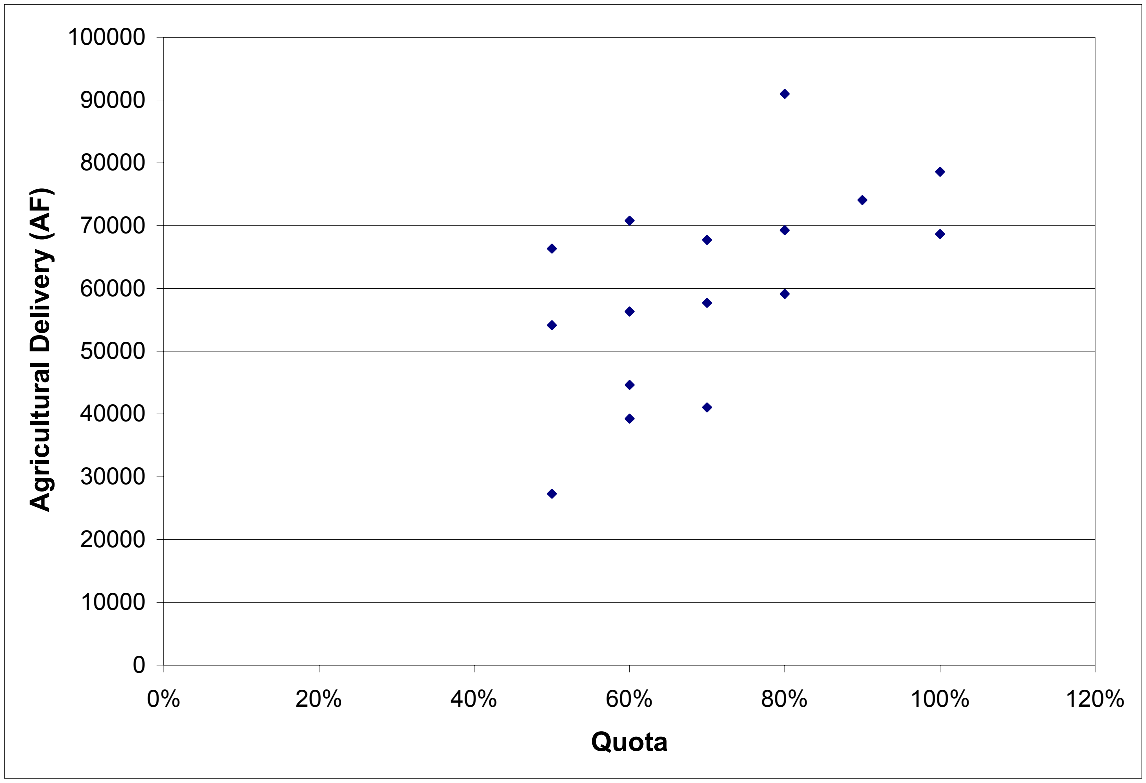

Figure 5-2. Annual agricultural delivery volume for a given quota

In dry years, the water users will generally make calls on the CBT water early in the season to transfer water to the plains reservoirs in anticipation of earlier irrigation demands. However, during wet years, the import water is typically not released at as high of a rate early in the season in order to conserve the water for use during the late summer months.

The CBT agricultural imports to the Poudre system enter the Poudre River downstream of FTDC2 and are subsequently diverted in their entirety upstream of POUC2, with some rare exceptions. The trans-basin import is therefore never seen at any forecast point in the system.

Because of the nature of this transfer, in modeling the system the Horsetooth import is imported directly to the simulated Plains reservoir after passing through a series of synthetic reservoirs, as described in the RES-J section below. The import acts as a supply to the simulated Plains reservoir to fulfill crop demand pulling water from the reservoir. Since the water never enters the Poudre River, the daily timing of the imports is not critical. The RES-J simulation attempts to capture the import transfer timing and carryover effects, and the volume of the import is pre-computed based on other modeling states.

A correlation was developed that related the areal-averaged, simulated snow water equivalent (SWE) in the upper elevation zones of EHNC2 and NCHC2 to the annual quota percent on April 15. The SWE was assumed representative of the potential water availability across the Poudre system and was expected to be inversely related to the annual quota (***Figure 5-3***). The relationship between simulated SWE and quota was used in a LOOKUP operation to set the pool elevation of the QUOTA reservoir and corresponding import volume each year. Although the LOOKUP operation computes a value every time step, the resulting time series is only queried on April 15 by RES-J.

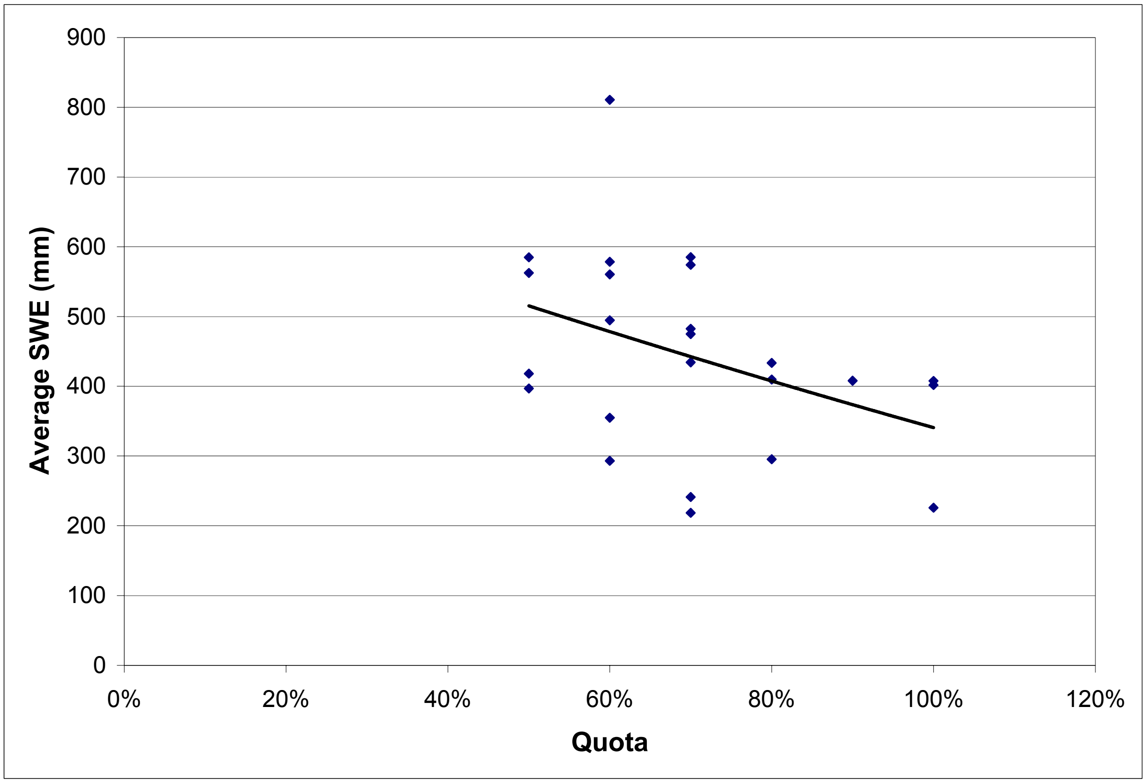

Figure 5-3. Relationship between SWE on April 15 and quota percentage (1987 – 2002)

5.3.5.3 Diversion for Municipal Water Treatment Plant

A diversion for Greeley municipal use occurs between FTDC2 and POUC2. This diversion was simulated using fixed monthly values implemented in a CHANLOSS operation.

5.3.5.4 Additional Diversion from POUC2 Sub-basin

Water is diverted from the Poudre at multiple locations in the POUC2 sub-basin. One diversion supplies water for Greeley municipal use, as described above. The remaining diversions are all for agricultural uses and generally divert water to one of the irrigation reservoirs in the POUC2 and GRPC2 sub-basins.

In modeling the agricultural diversion, the aggregated diversion was broken into three components:

1) Trans-basin imports to EHNC2 that are diverted to the Plains reservoir.

2) Trans-basin imports from Horsetooth that enter the river and leave the river before POUC2.

3) Unregulated and regulated runoff from the upper sub-basins that is diverted to the Plains reservoir.

Item 1 is computed as described in ***Section 5.3.2***. Although this flow may be held in the EHNC2 reservoirs for a time, during the calibration of the total flows at FTDC2, it improved the calibration to allow the EHNC2 trans-basin import to flow downstream without regulation. The trans-basin imports are diverted entirely to the Plains reservoir between FTDC2 and POUC2. The method for modeling item 2 is described in the RES-J section below, but since the Horsetooth imports both enter and exit the river between forecast points, the imports may be put directly into the Plains reservoir. The following describes how item three is modeled.

First, a net "observed" historic diversion time series was computed. The total aggregate diversion was previously generated for the sub-basin. The EHNC2 imports (component 1) and Horsetooth imports (component 2) are subtracted from the total diversion between FTDC2 and POUC2 to create this net observed historic diversion time series.

The net "observed" historic diversion was correlated with the simulated unregulated runoff at FTDC2 (approximated as 65% of the EHNC2 sub-basin natural runoff and 100% of the FTDC2 sub-basin natural runoff) on a monthly basis. The correlation values were used to develop a variable percentage CHANLOSS operation, as was done for the FTDC2 diversion and the EHNC2 imports. An upper limit was again applied using a separate CHANLOSS function.

Although the unregulated natural runoff is used as the basis to compute this diversion, the water that is diverted is provided from other sources (e.g. releases from the EHNC2 reservoirs). As such, the computed diversion is greater than the unregulated natural runoff in the late summer months. In the modeling, it was assumed that this water would be available for diversion. The computed diversion is applied as an inflow to the Plains reservoir before determining the flow available for diversion, which is dependent upon the output of the RES-J computations. Therefore, it is possible that there would not be sufficient water to supply the full diversion volume, and therefore the reservoir inflow volume would have been incorrect. However, this error is relatively minor. The diversion is limited in the final flow computation at POUC2, so the error only affects the Plains reservoir contents, which has a relatively small effect on the total flow at POUC2 and GRPC2. Finally, during the calibration, there were few cases when the computed diversion exceeded the available water in the stream.

In evaluating the diversion simulation, the actual diversion is significantly lower than the simulated diversion in some wet years. A means was devised to reduce the diversion during wet periods by computing an indicator of the amount of precipitation over the past 45 days (1½ months). The MAP time series was passed through a 45-day unit hydrograph with equal ordinates for every time step. A LOOKUP operation was then used to determine when the accumulated precipitation over the last 45 days exceeded a threshold amount, at which point the accumulated volume was subtracted from the simulated diversion. This served to reduce the simulated diversion in wet years. The impact of this adjustment may be seen in the second plot in the PLOT-TS operation of the POUC2div calibration deck.

5.3.6 GRPC2 Regulations

Two different regulations in the GRPC2 sub-basin could be computed prior to the RES-J modeling. These included the potential riparian agricultural diversion and the municipal and industrial return flows.

5.3.6.1 Riparian Agricultural Diversion

This represents the aggregate diversions located between POUC2 and GRPC2 for agricultural use. To model the diversions, a consumptive use model with the same area used to compute crop demand was used. A large source was provided to the consumptive use model so it was never supply-limited. The monthly crop coefficients were adjusted to match the diversion patterns. A scaling factor was then used to reduce the volume of diversion to match the aggregate observed diversion.

The crop demand of the irrigated riparian area may be supplied either by irrigation or by precipitation. If there is sufficient precipitation, the irrigation will be reduced because of the reduced demand. However, with a small amount of precipitation, the irrigation will continue at the same rate. These effects can be seen in the observed diversion time series. This practice is simulated in a similar manner to the diversion reduction computation for the POUC2 diversion. The MAP time series for GRPC2 was passed through a 14-day, constant volume unit hydrograph (assuming the precipitation over the past two weeks represents the period that farmers would consider for reducing their irrigation). The simulated flow produced by this unit hydrograph is passed through a LOOKUP operation to ignore accumulated precipitation volumes below a certain volume. If the accumulated precipitation exceeds the threshold, the diversion is reduced by the volume of accumulated precipitation.

The actual diversion may be reduced as well in dry years due to supply limitations. The computations in this preprocessing step assume a large enough supply to fulfill the diversion, but the actual diversion amount is computed after the RES-J processing when the available flow in the stream is known, at which point the diverted flows would be reduced if there was a limit in supply.

Return flows from the riparian irrigation are computed after the RES-J processing as well, as described in ***Section 5.5.1***.

5.3.6.2 Municipal and Industrial Wastewater Return Flows

Multiple wastewater treatment facilities return flows to the river between POUC2 and GRPC2. These aggregated return flows were simulated using constant monthly values implemented in a CHANLOSS function.

5.4 RES-J Simulation

The RES-J model consists of a number of reservoirs and reaches together with associated methods. The pre-computed time series generated in the above steps were used as input to the RES-J simulation. The RES-J topology and withdrawals to nodes are shown in the diagram in ***Figure 5-4***. Details concerning each component are included in the subsequent sections, including specific inflows, outflows, and transfers between reservoirs. The reservoirs were calibrated using the time series of diversions to and releases from storage computed as described in ***Section 2.2.2*** and by comparing simulated to total flows at each forecast point where observed streamflow were available. As many observed time series as possible were used in the simulation during calibration to isolate the reservoir effects.

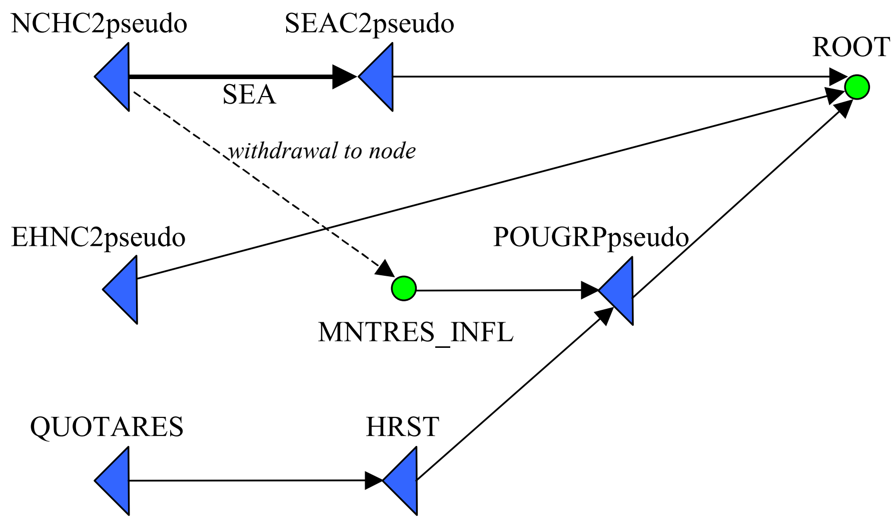

Figure 5-4. Poudre River RES-J model diagram

5.4.1 Reservoir EHNC2pseudo

The EHNC2pseudo reservoir is a composite reservoir representing all of the reservoirs upstream of EHNC2. Inflow to the reservoir includes a fraction of the EHNC2 headwater inflow. This fraction is based on date, reflecting the estimated melt / runoff patterns from low to high elevations and the basin area controlled by the reservoirs. Calibration suggested that water imported to the basin is best simulated without storage in the reservoir. Therefore, it is not included in the inflow to the EHNC2pseudo reservoir, but contributes to total flow at EHNC2 and FTDC2 before being entirely diverted to the POUGRPpseudo plains reservoir above POUC2. Withdrawal to meet Fort Collins municipal demands is computed using a SETWITHDRAW method. This withdrawal occurs physically below EHNC2 but above FTDC2. Release from the reservoir is governed by a SETRELEASE method and a SPILLWAY method. The SETRELEASE method represents releases to meet in-stream flow requirements and water rights that were not clearly discernable in the study. The SPILLWAY method handles uncontrolled spill. Note that all withdrawals and releases (controlled and uncontrolled) from the reservoir are physically made through the same outlet works into the downstream reach. They are divided here for modeling purposes.

5.4.2 Reservoir NCHC2pseudo

The NCHC2pseudo reservoir is a composite reservoir representing Halligan reservoir as well as a small reservoir near the basin divide that re-regulates trans-basin imports. Inflow to the reservoir includes the NCHC2 headwater inflow plus the pre-computed trans-basin imports. Release from the reservoir is governed by a SETRELEASE method that represents releases in excess of releases for diversion to the POUGRPpseudo reservoir. A withdrawal to the POUGRPpseudo reservoir is computed as well using a SETWITHDRAW method. It follows a fixed monthly demand and is specified as a withdrawal to another component, node MTNRES_INFL, upstream of the POUGRPpseudo reservoir. Note again that all releases from the reservoir are physically made through the same outlet works into the downstream reach, but are divided here for modeling purposes.

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5.4.3 Reach SEA

The SEA reach is between Halligan and Seaman and is used to route flows between the reservoirs using a Lag-K method.

5.4.4 Reservoir SEAC2pseudo

The SEAC2pseudo reservoir represents Seaman reservoir, although the elevation characteristics are synthetic, and is therefore labeled “pseudo”. The reservoir is defined with a SETRELEASE method to represent typical monthly releases plus a SPILLWAY method for uncontrolled spill.

5.4.5 Node MTNRES_INFL

The MTNRES_INFL node receives the EHNC2 trans-basin import and withdrawals from NCHC2pseudo reservoir. This node is topologically upstream of the POUGRPpseudo reservoir so that flow will pass directly to the POUGRPpseudo reservoir.

5.4.6 Reservoir QUOTARES

The QUOTARES reservoir provides functionality for trans-basin imports through Horsetooth reservoir. It receives a volume of water, representative of the current year’s import quota, on April 15th as a pool elevation that is assigned by an ADJUST method. This pool elevation is calculated outside of RES-J through a LOOKUP operation from the pre-computed quota volume time series. Until July 15, the water in QUOTARES may be transferred to the HRST reservoir at limited rates if HRST reservoir drops below 1.5% capacity, ensuring that HRST provides sufficient water to meet POUGRPpseudo reservoir withdrawal demand. From July 15th through the 17th, any water remaining in QUOTARES is released to HRST as specified by a SETELEVATION method with a target pool of zero. The remainder of the year, the pool elevation remains at zero, as does the release.

5.4.7 Reservoir HRST

The HRST reservoir provides trans-basin import water to the POUGRPpseudo reservoir while ensuring proper handling of annual water quotas. From April 20th to July 1st, HRST reservoir attempts to maintain the POUGRPpseudo reservoir pool elevation at or above 50% capacity and at or below 80% capacity. This is accomplished using a BALANCE method, where the BALANCE release from HRST is constrained to be less than some maximum. The maximum release rate is set using a SETRELEASE method, and the BALANCE release is kept below the SETRELEASE maximum using a SETMIN method. If HRST reservoir is sufficiently drawn down, release from QUOTARES will provide additional water to HRST to continue maintaining the POUGRPpseudo reservoir release. From July 1st to July 15th, HRST will attempt to transfer any water remaining in its storage so that the POUGRPpseudo reservoir is between 90 and 95% capacity. This is done using a BALANCE method. In the physical system, water from the previous year’s quota can be used until July 15th, at which point it is counted toward satisfying this year’s quota. To simulate the quota rollover, an ADJUST method resets the HRST pool elevation to 0 on July 15th. Immediately thereafter, the releases from QUOTARES transfer the new year’s quota (or the remainder thereof) to the HRST reservoir. From July 18th until the end of October, HRST reverts to the same mode of operations experienced from April 20th through July 1st.

5.4.8 Reservoir POUGRPpseudo

POUGRPpseudo is a composite reservoir representing the storage reservoirs in the plains. In addition to the inflow from the upstream node at MTNRES_INFL and the HRST reservoir (imports from Horsetooth reservoir), the inflow to this reservoir includes diversions just upstream of FTDC2 and a diversion between FTDC2 and POUC2. The primary SETWITHDRAW method uses a pre-computed consumptive use demand time series. This withdrawal is constrained to be less than some maximum withdrawal rate by using a SETMIN method with a SETWITHDRAW method specifying the maximum withdrawal rate. A SETSUM method then adds the constrained withdrawal to the results of a SETWITHDRAW method representing evaporation from the reservoir. The RAINEVAP method was not used because the surface area of the composite reservoir does not correspond with the true surface area of the actual reservoirs. Under normal circumstances, no other release from the reservoir is computed. Under very high storage conditions, a SPILLWAY method functions to handle overfilling. The flow calculated by the SPILLWAY method best represents accumulated errors in inflow or withdrawal estimates to or from the reservoir rather than actual spill from the plains reservoirs. Recognizing the parameterization uncertainties and tendency to accumulate errors over time, it was considered unwise to apply the uncontrolled spill back to the river, as doing so generally reduced the calibration accuracy and did not reflect regulation practices. Instead, the uncontrolled spills were considered a means of accounting for accumulated error and were removed from the system.

5.4.9 Node ROOT

The ROOT node is downstream of all other components so that they all tie together in RES-J. No meaningful results are computed at the node.

5.4.10 RES-J Conditional Statements

A TRUE condition is used to trigger most methods in the RES-J model, causing them to execute each time step. Certain other conditions are tested for the QUOTARES and HRST reservoirs to enable their functionality. These conditions are primarily date checks, but one also includes query of the pool elevation state at the HRST reservoir.

The RES-J model contains the necessary components to simulate the effects of storage and release of runoff in the basin. The computation of total flow at forecast points is handled in the final part of the simulation.

5.5 Post-Calculated Return Flows and Forecast Development

The final steps in the third modeling approach involved computing agricultural return flows and pulling together the various time series components to compute total flow at each sub-basin outlet.

5.5.1 Return Flow Computations

A large aquifer exists beneath POUC2 and GRPC2 that contributes significantly to flows in the lower reaches and to irrigation water to meet consumptive use. Significant complexities exist in these segments, including diverted water application, seepage to deep groundwater, groundwater pumping and application, return flow to the river, and potential re-extraction of this returned flow. In simulating these interactions, the composite diversions within each sub-basin were modeled as described in ***Section 1.1***, assuming sufficient water will be available to supply the diversion. The return flows from the POUGRPpseudo plains reservoir and the local GRPC2 irrigation diversions are simulated as described in this section. The actual amount of water diverted at each point is limited based on the water that is available in the river, as described in the following section.

The pool elevation time series from the POUGRPpseudo reservoir was used as a surrogate for wet or dry conditions for the return flow computations. During calibration, the return flows were more accurately represented using this relationship with the POUGRPpseudo reservoir pool elevation than the reservoir outflows. This pool elevation reflects long-term water availability, and thus can indicate the amount of irrigation application and subsequent return flows. LOOKUP tables translated the pool elevation into potential return flows, one for above POUC2 and one below POUC2 in the GRPC2 sub-basin. After computing the return flow volume, they were then routed using a large lag and attenuation value in a LAG/K operation. The POUC2 returns were then applied at POUC2. In the GRPC2 sub-basin, 75% of the groundwater return was made available for the reach's primary diversion. The remaining 25% was applied downstream of the diversion at GRPC2.

The potential primary diversion from GRPC2 was pre-computed as described in ***Section 5.3.6.1***, assuming sufficient available flows. The actual diversion was constrained by the available flows at the point of diversion. Ten percent of the actual diversion was computed and routed using a large lag and attenuation value in a LAG/K operation to represent riparian return flows.

5.5.2 Forecast Development

The following describes the development of total flow at each forecast point. These were computed using a series of ADD/SUB and WEIGH-TS operations. Additional details concerning the different time series are included in ***Appendix A***.

5.5.2.1 EHNC2

The total flow has the following components:

- A fraction of the total basin runoff (representing runoff from the area below reservoir regulation).
- Release from the EHNC2pseudo reservoir.
- Withdrawal from the EHNC2pseudo reservoir for Fort Collins municipal use. The actual diversion works for this withdrawal is between EHNC2 and FTDC2.
- EHNC2 trans-basin imports which are essentially passed through the reservoir (without consideration at EHNC2pseudo reservoir in RES-J). The point at which these flows are diverted to the plains reservoirs is between FTDC2 and POUC2.

5.5.2.2 NCHC2

The total flow has the following components:

- Reservoir release from NCHC2pseudo.
- Reservoir withdrawal from NCHC2pseudo that has to pass by the forecast point before physically being withdrawn.

5.5.2.3 SEAC2

The total flow is simply the release from the SEAC2pseudo reservoir.

5.5.3 FTDC2

The total flow has the following components:

- EHNC2 runoff below reservoir regulation.
- FTDC2 local runoff.
- Subtraction of the pre-computed FTDC2 diversions.
- EHNC2 basin imports that are passed through the reservoirs. The point at which these flows are diverted to the plains reservoirs is between FTDC2 and POUC2.
- Release from the EHNC2pseudo reservoir.
- The SEAC2 flow.
- Any negatives that may arise due to subtraction of the FTD diversions are zeroed at this point.

5.5.4 POUC2

The total flow has the following components:

- Upstream flow from FTDC2.
- POUC2 local runoff.
- Subtraction of water for municipal (Greeley) use. Any negatives are zeroed.
- Subtraction of the EHNC2 basin imports. Any negatives are zeroed.
- Subtraction of the pre-computed POUC2 diversions to plains reservoirs. Any negatives are zeroed.
- Groundwater return flow calculated as a function of POUGRPpseudo reservoir pool elevation.

5.5.5 GRPC2

The total flow has the following components:

- Routed upstream flow from POUC2.
- 75% of the groundwater return flow calculated as a function of POUGRPpseudo reservoir pool elevation.
- GRPC2 local runoff.
- Fort Collins and Greeley municipal return flows.
- Subtraction of diversion for riparian irrigation from the sum of the above components. During low flows, the diversion will be limited by availability of the above components, leaving the remaining components to make up the flow at GRPC2. Any negatives are zeroed.
- Riparian irrigation return flow.
- 25% of the groundwater return flow calculated as a function of POUGRPpseudo reservoir pool elevation.

5.6 Calibration Statistics

Throughout the calibration process, various simulated and observed modeling components were visually and statistically compared in order to calibrate the models. The final simulation statistics are listed in ***Table 5-1*** for modeling approach 3. No observed time series were used during the simulation aside from MAP and MAT time series, and the simulations were not adjusted to observed flows at the outlet points. High flow bias statistics depict the values from the highest flow bracket of the STAT-QME output that contain at least 50 data points.

For comparison purposes, a natural flow simulation was made using the calibration decks from Approach 1 with no adjustments to observations. The simulated (natural) discharge was compared with the observed (regulated) discharge at each forecast point. The resulting statistics (***Table 5-2)*** demonstrate the importance of regulation modeling in the Poudre basin.

Table 5-1. Total flow calibration statistics for modeling approach 3

Sub-Basin	Simulated Total Flow (cmsd)	Annual % Bias	C.Coeff. Daily Flows	Daily RMS Error (cmsd)	Total Observed Flow (cmsd)	*(Daily RMS Error) / (Total Obs Flow)*	OBS=A+B*SIM (A, B)	High Flow Bias %
NCHC2	2.06	2.03	0.655	2.64	2.02	1.31	0.66, 0.66	-40.6
SEAC2	1.72	-3.85	0.763	3.03	1.79	1.69	0.19, 0.93	-35.8
FTDC2	8.44	3.27	0.920	5.47	8.17	0.67	0.45, 0.92	-4.0
POUC2	3.61	4.44	0.851	4.97	3.46	1.43	-0.24, 1.03	-26.3
GRPC2	4.43	1.15	0.851	4.60	4.38	1.05	0.05, 0.98	-26.9

Table 5-2. Statistics comparing natural flow simulations to total observed flows (Approach 1)

Sub-Basin	Simulated Total Flow (cmsd)	Annual % Bias	C.Coeff. Daily Flows	Daily RMS Error (cmsd)	Total Observed Flow (cmsd)	*(Daily RMS Error) / (Total Obs Flow)*	OBS=A+B*SIM (A, B)	High Flow Bias %
NCHC2	2.02	0.15	0.622	2.77	2.02	1.37	0.75, 0.62	-33.3
SEAC2	2.99	66.48	0.762	3.34	1.79	1.86	-0.66, 0.82	-34.6
FTDC2	10.16	24.37	0.905	7.27	8.17	0.89	0.45, 0.76	14.5
POUC2	10.62	206.85	0.764	13.19	3.46	3.81	-1.19, 0.44	31.5
GRPC2	11.81	169.70	0.615	15.48	4.38	3.53	0.66, 0.32	30.5

6.0 OFS IMPLEMENTATION

After fully developing each of the three modeling approaches described above, a verification analysis was conducted to help quantify the benefits of the different approaches. In order to compare the long-range probabilistic forecasting capabilities of each approach, each system of models was initialized in the NWS Operational Forecasting System (OFS). Operational requirements were considered during the initialization process to enable the forecasters at the MBRFC to view and modify appropriate modeling components in each approach to produce reasonable forecasts.

The MBRFC provided RTi with a copy of its operational fs5 files to be used as a starting point for the initialization. Three separate copies of the fs5 files were made and appropriate Apps_defaults tokens and directories were set up to allow each approach to be run independently from the others. Upon completion of the project, the MBRFC was supplied with the fs5 files and appropriate initialization files for each approach.

6.1 System Initialization

Many different components of the OFS had to be modified to incorporate the new segments of the Poudre River. Although the specific files varied for each approach, the basic steps remained the same.

- Set up the geo_data files. The MBRFC provided RTi with geo_data files, which were modified to include the new basin boundaries. The appropriate coordinate extents were set as well.
- Define new data types. For the third approach, QIN, SWE, and SPEL data types had to be added.
- Delete existing forecast and carryover groups. Since the forecast group definition was changed for the South Platte forecast group, the forecast and carryover group definitions had to be removed before redefinition. All the forecast and carryover groups in the system were deleted and later redefined.
- Delete old Poudre segments. The existing segment definitions for the Poudre sub-basins were removed.
- Define stations. A number of new stations had to be added for the MAT and MAP computations, as well as stations for the outlet points. Any observed data that would be entered in the system had to be added as well, such as the net regulation stations for Approach 2.
- Run Network.
- Delete old Poudre areas and basins. With the new sub-basin configurations in the Poudre, the existing basins and areas were deleted before their redefinition.
- Define new basins. The sub-basin boundaries provided by the MBRFC were used to define the new basins.
- Define new areas. Information from the MAP and MAT input decks was used to redefine the MAP and MAT computations for the new Poudre sub-basins.
- Define new techniques. The GENTRACE and FROST techniques were added for use with the NWS Ensemble Streamflow Prediction (ESP) program.
- Define new rating curves. Rating curves were provided by the MBRFC for the FTDC2 and NCHC2 streamflow stations and were added to the system.

- Define computational segments. The new computational segments were defined for each approach.
- Define new forecast and carryover groups. The appropriate segments were added to the SOPLATS forecast group to include the new segment definitions. A Special forecast group, POUDREVS, was added that included all the new Poudre River segments to facilitate the ESPVS verification.
- Run Order.
- Post SHEF data. Any observed diversion stations that are automatically filled required an initial SHEF message to permit the preprocessors to fill in the observed data. This applied only to Approach 2.
- Run preprocessors. The MAP, MAT, and RRS preprocessors filled in the required time series to permit the forecast system to be run using fcexec.
- Run fcexec to verify everything functioned properly. fcexec was run manually and using IFP to verify the system would run and the resulting plots made sense.
- Run ESP in the historic simulation mode for the system. A quality control comparison was made between the calibration simulation and ESP simulation at the outlet of GRPC2. The calibration decks were run for each modeling approach to produce an unadjusted total flow at GRPC2. The output time series was copied to the ESP time series directory as the "observed" discharge for GRPC2. The ESP Analysis and Display Program (ESPADP) was then used to compare the historic simulation mode traces for a modeling approach to the "observed" discharge traces, which in reality were the output from the calibration simulation. The traces from each time series should be identical, with the exception of the startup period when initial conditions still affect the simulation. This quality control step was used to identify potential errors in the initialization.

6.2 Segment Configurations

The segment definitions and configurations for modeling approaches 1 and 2 basically are straight conversions of the calibration segment definitions with the addition of stage-discharge conversions and Tulsa plots. The segment definitions for approach 3, on the other hand, combine multiple calibration decks to combine multiple components of the regulation modeling into single decks and provide better organization to the modeling. In addition, operations are included for inclusion of observations. ***Figure 6-1*** shows the segment configuration for Approaches 1 and 2, and ***Figure 6-2*** shows the segment configurations for Approach 3.

6.2.1 Approach 1 Segment Definitions

Each segment contains the hydrologic models to produce a natural flow simulation for the sub-basin. This includes the appropriate SNOW-17, SAC-SMA, UNIT-HG, and LAG-K models needed to generate local runoff and route flows between forecast points. STAGE-Q operations are included to convert between observed stage and discharge and from simulated discharge to stage. PLOT-TUL operations are included to display the modeling results at each location.

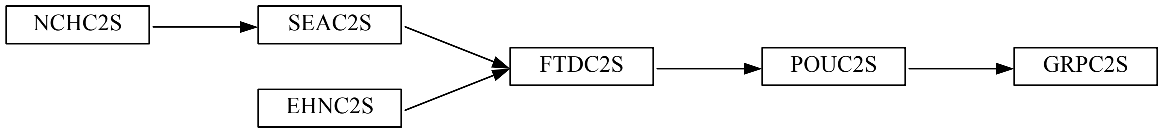


Figure 6-1. Segment configurations for modeling approaches 1 and 2

6.2.2 Approach 2 Segment Definitions

In addition to an observed time series of net regulation and return flows where appropriate, each segment contains the same hydrologic model components as in Approach 1. ADD-SUB operations are configured such that any resulting negative flows are set to zero during the ESP runs that utilize the observed net regulation time series.

6.2.3 Approach 3 Segment Definitions

The segment definitions for the third modeling approach are more complicated and combine multiple calibration decks to produce the final forecasts for each sub-basin outlet. ***Figure 6-2*** shows the segment configurations, and the following bullets describe the flow components modeled in each segment.

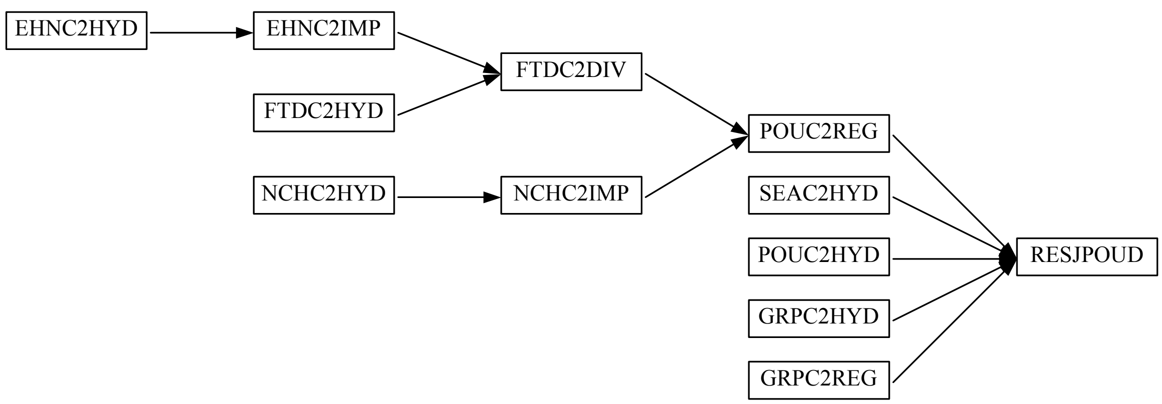


Figure 6-2. Segment configurations for Approach 3

- EHNC2HYD (and other *HYD segments): The local area runoff in each segment is computed. The local area runoff is used to compute a variety of other regulation components before being used in the RESJPOUD segment.
- EHNC2IMP: The trans-basin import into EHNC2 is computed as a separate segment.
- NCHC2IMP: The trans-basin import into NCHC2 is computed. Although this segment contains few operations, it is kept as a separate segment for clarity.
- FTDC2DIV: The diversion to the POUGRPpseudo plains reservoir from the FTDC2 segment is computed.
- POUC2REG: Four different regulations are computed: 1) The consumptive use crop demand on the POUGRPpseudo reservoir, 2) The Horsetooth Reservoir trans-basin import annual volume, 3) The diversion for the Greeley municipal water treatment plant, and 4) The net remaining diversion from POUC2 to the POUGRPpseudo reservoir.
- GRPC2REG: Two different regulations are computed: 1) The local GRPC2 agricultural diversion, and 2) The municipal and industrial wastewater treatment plant return flows.

- RESJPOUD: Flow components from all the above segments are read into this segment. A RES-J operation uses much of this information to model the releases and transfers of water between the reservoirs in the Poudre basin. After completion of the RES-J operation, the various flow components are combined to produce the total streamflow forecasts at each outlet point. Finally, various components of the flow at each outlet point are plotted to assist forecasters in understanding and manipulating the forecasts at each location.

6.3 Operational Forecasting Considerations

If modeling approach 1 or 2 is implemented, the operational activities are relatively straightforward and follow traditional forecast development steps. In modeling approach 3, however, the operational activities would vary due to the complexity of the system. Some recommendations concerning these operations may facilitate forecast generation.

6.3.1 Approach 1

The first modeling approach was developed as a baseline model and was not intended for operational use. If the approach were implemented, additional operations would be required to modify the flow to some extent for regulation, as in Approach 2.

6.3.2 Approach 2

Real-time modifications for the second modeling approach would involve two basic components. The first would involve modifications to the natural hydrologic response in each sub-basin using typical mods such as RRICHNG or SACBASEF. The second component would involve using a TSCHNG mod or entering observations via SHEF messages of the net regulation in each sub-basin, and the return flow in the POUC2 and GRPC2 sub-basins, to better capture regulation effects in the basin. If observations were entered, these time series would represent aggregated regulation, and therefore would be used in the OFS as adjustment tools for improving forecasts rather than true observations.

In order to enter net regulation time series, SHEF messages could be generated and posted to the NWSRFS using the following time series/station identifiers:

- Net Regulation Time Series: EHNREG, NCHREG, SEAREG, FTDREG, POUREG, and GRPREG
- Return Flow Time Series: POURET and GRPRET

Under the current time series definitions, it should be noted that the net regulation time series are defined as an addition to the natural runoff. As such, a trans-basin import would be entered as a positive value, and a diversion from the river would be entered as a negative value. If the segment definitions were altered to reverse the sign of the time series, the net regulation CARD data file, generated using the calibration decks and referenced for ESP forecasts, would need to be modified as well.

The net regulation and return flow time series are defined in the system to automatically fill missing observations by carrying the latest observation forward. Therefore, if no data are entered for one of the time series, the time series will reflect the latest modifications and may not be representative of the current states.

6.3.3 Approach 3

Due to the complexity of the third modeling approach, the segment definitions do not follow a typical up to downstream sequence, but instead represent different modeling components that are all pulled together in the final segment. A number of recommendations may assist operational forecasters using the system.

6.3.3.1 Operational Forecasting Routine

Under typical circumstances, the forecaster would step through every segment in a system, making appropriate adjustments before running the next segment. In the Poudre basins, however, numerous initial segments pre-compute various components of the flow. No flow observations are available for determining appropriate forecast modifications before the RESJPOUD segment. In this segment, numerous PLOT-TS plotting operations have been created to display the total flow at each forecast location, components comprising the total flow at each location, and synthetic reservoir elevations. Therefore, it is recommended that all segments before the RESJPOUD segment be initially run without reviewing the results. Then, the total flow may be reviewed at each location along with the flow components. Based on this review, in the event the forecast does not accurately reflect the observed flow, the forecaster could potentially discern the component of flow that is causing the discrepancy between the simulation and observation. The forecaster could then return to the appropriate segment used to generate that specific flow component, make appropriate modifications, rerun the system through the RESJPOUD segment, and review the total flow plots to determine if the modifications improved the forecast.

6.3.3.2 Routine Forecast Adjustments

The following flow components may be modified as described.

- Local natural runoff in each segment. These may be modified using typical mods such as RRICHNG or SACBASEF in the *HYD segments.
- Pool elevation adjustments are built into the RES-J model to allow modification of the pool elevation in each of the four major reservoirs of the Poudre system (EHNpseudo, NCHpseudo, SEApseudo, and POUGRPpseudo). The adjustment would be accomplished using a TSCHNG mod or by entering a pool elevation observation via SHEF data for the EHNRESPE, NCHRESPE, SEARESPE, or POUGRPPE PELV time series. It should be noted that the pool elevation ranges from 0 – 100 feet for each reservoir and does not translate directly from any particular pool elevation observation.
- The EHNC2 aggregate trans-basin import (see ***Section 5.3.2***) may be modified by inputting SHEF data for the EHNC2IMP QIN time series or by using a TSCHNG mod on the simulated time series.
- The NCHC2 aggregate trans-basin import (see ***Section 5.3.3***) may be modified by inputting SHEF data for the NCHC2IMP QIN time series or by using a TSCHNG mod.
- The FTDC2 aggregate diversion (see ***Section 5.3.4***) may be modified by inputting SHEF data for the FTDC2DIV QIN time series or by using a TSCHNG mod.
- The POUC2 net aggregate diversion (see ***Section 5.3.5.4***) may be modified by inputting SHEF data for the POUC2DIV QIN time series or by using a TSCHNG mod.
- The GRPC2 aggregate riparian diversion (see ***Section 5.3.6.1***) may be modified by inputting SHEF data for the GRPC2DIV QIN time series or by using a TSCHNG mod.

- The irrigation return flows from the POUGRPpseudo plains reservoir into the POUC2 and GRPC2 segments (see ***Section 5.5.1***) may both be modified by inputting SHEF data for the POUC2RET and GRPC2RET QIN time series, respectively, or by using a TSCHNG mod on the simulated time series.
- The NCHpseudo reservoir withdrawal models the diversion to the North Poudre Canal between NCHC2 and SEAC2. It may be modified by inputting a SHEF data message for the SEAC2DIV QIN time series or by using a TSCHNG mod. This is one regulation in the system that represents a single diversion as opposed to a group of regulations. Information concerning the magnitude of the diversion could be determined by comparing the real-time observations at the NCHC2 sub-basin outlet (USGS station 06751150, below Halligan Reservoir) to the USGS station 06751490 observations at Livermore, located just downstream of the diversion but upstream of the SEAC2 reservoir. The difference between these observations should equal the diversion.

Flow observations were not included for every component of the flow in the system for two reasons. First, some flow components may be modified by changing other model states. For instance, the release from a reservoir may be modified by changing the pool elevation in the reservoir. Other flow components are relatively minor and vary little over time. These regulations could be modified using a TSCHG mod, although the effects of the change would not persist beyond the time steps that were altered.

All of the above regulations are representative of groups of imports or diversions or reservoirs, with the exception of the NCHpseudo reservoir withdrawal. Therefore, no actual observations of a single diversion or trans-basin import could be used to directly modify the regulations. However, observations could be used as an indicator of the magnitude of a given regulation.

In order to update the synthetic reservoir elevations, it may be possible to obtain information from the NCWCD or the Poudre River water commissioner. Although they may not provide actual reservoir levels, they may be able to assess the relative conditions of the system, such as how full the plains reservoirs are, which could be used to adjust the POUGRPpseudo reservoir level.

6.3.3.3 NCWCD Annual Quota Adjustment (Horsetooth Import)

Every year on April 15th, the NCWCD issues an annual quota that determines the water availability for its users, as described in ***Section 5.3.5.2***. This annual quota is simulated based on the SWE in the upper elevation zones, and is used to set the annual CBT trans-basin import volume. However, if the annual quota percentage could be obtained from the NCWCD, the actual annual quota could be utilized instead of the simulated quota. This would potentially improve the long-range forecasts that would reflect the effects of the trans-basin import volume on the system.

Although the quota is computed at every time step, it is only utilized by RES-J on April 15 to set the pool elevation of the QUOTA reservoir. Therefore, in order to enter the annual quota, SHEF messages should be generated for the OBSQUOTA PELV time series for every time step on April 15, or a TSCHG mod could be used to manually adjust the simulated pool elevation time series for that date. The quota SHEF data values should be set on a scale of 0 – 100 feet, where the elevation in feet equals the observed quota percent.

After running the system, the QUOTA reservoir pool elevation should be reviewed for the dates before and after April 15 (time series QUOTA_PE, data type SPEL). The pool elevations for all reservoirs are output in tabular form using the LIST-FTW operation. Before April 15, the pool elevation in QUOTA should be zero, and on April 15 should jump to the quota percentage specified by the user.

No observation discharge time series was included for the Horsetooth trans-basin import because the monthly volume of the import is modeled instead of the daily distribution. Therefore, unless the observations were consistently available throughout the year, entering sporadic daily import observations would affect the modeling accuracy. If there appears to be a problem caused by the import, it could be adjusted by modifying the pool elevation of the POUGRPpseudo plains reservoir, as described previously.

7.0 VERIFICATION

7.1 Probabilistic Analysis Background

The analysis of regulation modeling and comparison of the accuracy of ESP forecasts generated using each modeling approach requires the evaluation of the probabilistic variables generated from an ESP forecast. This is accomplished by generating and analyzing a suite of historical probabilistic forecasts ("hindcasts") for each approach using statistical measures designed specifically for evaluating probabilistic forecasts.

Sample ESP products were prepared for each of the three approaches for a forecast date of April 1, 2003 at FTDC2. The ESP products include weekly histogram plots of flow, stage, and volume, and 90-day exceedance plots of peak flow and stage, minimum flow and stage, and volume. All sample products are included in ***Appendix B***.

In the sample ESP products, Approach 1 generates higher discharges than Approaches 2 and 3, although the differences would be more pronounced at the downstream forecast points. The differences between Approaches 2 and 3 can be seen most clearly in the weekly histogram plots. Approach 2 tends to generate forecasts with less certainty than Approach 3 early in the forecast. The middle band of probability is much wider for Approach 2. The uncertainty associated with the forecasts using both Approach 2 and 3 increases as the forecast extends farther into the future, as the initial conditions influence future events to a lesser degree.

7.1.1 Tools

The ESPVS program was developed for generating historic ESP forecasts that can be used to assess the accuracy of ESP forecasts. A separate program, ProbVS, provides a statistical analysis of the data output by ESPVS.

The ESPVS program first runs a historic simulation of the entire historic period of record (in this case, 1988 through 2003). The ESPVS program saves carryover model states from the historic simulation for every year on the date that ESP forecasts are being analyzed. The ESPVS program then steps through each year and uses the saved carryover states from the historic simulation to run a conditional simulation for that year. The conditional simulation generates a series of possible flow scenarios, referred to as an ensemble. After completing all the runs, the ESPVS program will have generated ensembles for every year beginning on the same day of the year. This suite of ensembles (one ensemble for each year in the record) can then be analyzed statistically using the ProbVS program.

The ProbVS program provides statistical analysis of the data output by ESPVS. This prototype program is based on the verification research of Franz and Sorooshian (2002). The research proposed and demonstrated the use of four statistics for verification of probabilistic hydrologic forecasts: Ranked Probability Score (RPS), Ranked Probability Skill Score (RPSS), Discrimination, and Reliability. The ProbVS program queries the sets of ESP ensembles prepared by ESPVS through iterative calls to ESPADP. The ProbVS program instructs ESPADP to extract specific data and exceedance probabilities from the traces, which it subsequently ingests. It then analyzes the ensembles by computing each of the above statistics. For each requested statistic, four files may be output: data echo, internal worktables, results table and XML formatted results.

7.1.2 Scope of Evaluation

Based on the plan defined in the scope of work, ESPVS was run twice—once for each of two dates of investigation, April 1 and July 1. Water years 1988 through 2003 were used, as this was the limiting period due to the record of observed diversions required for approach 2. The ProbVS program was run several times to extract statistical information for three forecast points (FTDC2, POUC2, and GRPC2), three variables (accumulated volume, maximum flow and minimum flow), and a 90-day forecast window. Based on the results, several additional cases were analyzed to provide insight.

7.2 Verification Statistics

As mentioned above, there are four basic statistical measures generated by ProbVS. They are: 1) Ranked Probability Score (RPS), 2) Ranked Probability Skill Score (RPSS), 3) Reliability, and 4) Discrimination.

An ESP forecast is often displayed as a continuous probability distribution function where the probability is distributed over the range of the ensemble trace values. The statistics used to evaluate ESP forecasts, however, require that the ensemble be discretized. To do this, the forecast variable from individual ensemble members are sorted into bins, where each bin represents a range of possible values of the variable. For example, a water supply forecast may have three bins that represent the lower, middle, and upper one-third of the historical observations of the 90-day volume. Each bin is characterized by the volume associated with its particular portion of the historic data record (climatology). The percentage of ensemble members with values that are within the range of each bin represents the likelihood that the future streamflow will also have a value within that range. The number of bins can vary and can be chosen based on the preferences of the user. For the RPS and RPSS statistics, seven bins of approximately equal frequency of occurrence in the historical observations were chosen. For the reliability and discrimination, three bins were chosen representing low, medium, and high flow or volume ranges. The same bins were applied to all three approaches for a given forecast point, date, forecast window, forecast variable, and evaluation statistic.

For the reliability and discrimination statistics, three bins were used instead of seven because the number of bins sets the number of data points used to generate the reliability and discrimination plots for the different bins, as described in ***Section 7.2.2*** and ***Section 7.2.3***. With the RPS and RPSS statistics, utilizing seven bins instead of three appears to reduce the sensitivity of the RPS statistics to the bin designations. With fewer bins, if an approach discriminates well and consistently forecasts close to the observation, yet the observation is in a different bin than the forecasts, the approach will be heavily penalized. However, the same is not true with a larger number of bins. Comparisons with three and five bin RPSS computations are also presented.

7.2.1 RPS and RPSS

The RPS is a measure of overall forecast accuracy. For a given forecast variable it is computed as follows:

1. For each ESP ensemble year, the ProbVS program determines the probability of the forecast variable falling within each defined bin. The same probability also is calculated for the historical observations, also referred to as “Climate”.

2. For each ESP ensemble year the bin associated with the observed value of the forecast variable is identified and compared with the forecast probabilities. For each bin, the cumulative probability of having the forecast variable occur in that or a lesser bin is computed, as well as the frequency of the observation occurring in that or a lesser bin (the cumulative frequency of occurrence for bins less than

the bin in which the observation occurs is zero, and for the bin in which it occurs and all larger bins it is one).

3. For each bin, the difference between the cumulative forecast probability and the cumulative observed frequency is computed and squared. The sum of the squares for each bin is the RPS for that ESP ensemble year. ***Table 7-1*** illustrates the computation of RPS for a single year, including both the climate and forecast RPS.

4. The overall RPS is computed as the average of RPS values for each ESP ensemble year. ***Table 7-2*** illustrates the computation of overall RPS from the RPS for individual ensemble years.

The largest possible value for RPS is equal to one less than the number of bins. The RPS can be difficult to understand independent of other information to reference against. A useful comparison may be made between two forecasts, as is done in computing the RPSS. The RPSS is computed as the percent difference between the RPS of a reference forecast and the forecast of interest. It may be computed for individual ensembles or using the average RPS value from a group of ensembles. The ProbVS program automatically computes the RPSS for a set of ensembles using the historical observations as the reference forecast. The computation of RPSS is shown for a single year in ***Table 7-1***, and for individual years and all years in ***Table 7-2***.

Table 7-1. Sample RPSS statistics for one year (July 1 Volume at FTDC2, 1988)

```
    Statistics for 1988 ( observed was 44914.168 )

Climate                                                           2
         >=          < |    Prob     Obs CumProb  CumObs |  (CP-CO)
-----------------------+--------------------------------+--------
      0.000  32209.000 |   0.143   0.000   0.143   0.000 |   0.020
  32209.000  38331.000 |   0.143   0.000   0.286   0.000 |   0.082
  38331.000  54548.000 |   0.143   1.000   0.429   1.000 |   0.326
  54548.000  71602.000 |   0.144   0.000   0.572   1.000 |   0.183
  71602.000  84783.000 |   0.143   0.000   0.715   1.000 |   0.081
  84783.000  91360.000 |   0.143   0.000   0.858   1.000 |   0.020
   91360.00            |   0.142   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                 RPS =     0.713

Forecast                                                          2
         >=          < |    Prob     Obs CumProb  CumObs |  (CP-CO)
-----------------------+--------------------------------+--------
      0.000  32209.000 |   0.000   0.000   0.000   0.000 |   0.000
  32209.000  38331.000 |   0.000   0.000   0.000   0.000 |   0.000
  38331.000  54548.000 |   0.875   1.000   0.875   1.000 |   0.016
  54548.000  71602.000 |   0.125   0.000   1.000   1.000 |   0.000
  71602.000  84783.000 |   0.000   0.000   1.000   1.000 |   0.000
  84783.000  91360.000 |   0.000   0.000   1.000   1.000 |   0.000
   91360.00            |   0.000   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                 RPS =     0.016

                                                RPSS =    97.809
```

Table 7-2. Sample summary RPSS statistics (July 1 Volume at FTDC2, 1988)

Year	RPSc	RPSf	RPSS
1988	0.713	0.016	97.809
1989	0.713	0.000	100.000
1990	0.715	1.000	-39.845
1991	0.571	0.766	-34.197
1992	0.713	0.004	99.452
1993	1.861	0.910	51.088
1994	1.141	1.004	12.001
1995	1.861	0.000	100.000
1996	0.715	0.195	72.687
1997	1.145	1.070	6.506
1998	0.715	1.000	-39.845
1999	1.145	0.352	69.290
2000	1.855	2.004	-8.033
2001	1.141	1.016	10.974
2002	1.855	0.004	99.789
2003	0.571	1.227	-114.989
Average	1.089	0.660	39.372

Table 7-3 summarizes RPS and RPSS results for each date, forecast point, forecast variable, and modeling approach specified in the scope of work. Inspection of the results indicates that the RPSS for each of the three approaches is often negative, indicating that in those cases there is no improvement in the RPS statistic over forecasting using the historical (climatological) frequency distribution. A review of the annual RPS values showed that for a given forecast many of the years may have had high correlation between forecast and observed values, but that in one or two years a pronounced condition in the initial states (wet or dry) was followed by an opposite trend in the climate, resulting in an observation in the opposite direction of the forecast. For these years, the RPS is sufficiently large to spoil the average RPS for all years such that a low or negative RPSS results when compared with climatology. Because the climatological distribution spreads the probability uniformly over each range, the penalty on RPS for abnormal years is less significant than for the forecast distribution. This effect is amplified because the RPS is calculated based on the square of the cumulative probability differences.

Because the use of a squared term tends to severely penalize forecasts with high probabilities when the observation ends up in a distant bin, RTi computed an alternative statistic, an adjusted ranked probability score (ARPS) that uses the absolute value of the difference between the cumulative probability distributions for each year, instead of the squared difference. Like RPS, this statistic also has a maximum value equal to one less than the number of bins, but cannot be compared directly with the RPS, although it is intended be compared with ARPS for a reference forecast. A skill score (ARPSS) is also associated with this statistic. It should be noted that these two statistics (ARPS, ARPSS) are not mentioned in ESP verification literature, but were computed as part of this analysis to provide additional insight into the verification analysis. The ARPS and ARPSS are tabulated together with the RPS and RPSS statistics in ***Table 7-3***.

Table 7-3. Summary of RPSS and adjusted RPSS statistics for each verification location and date

FTDC2 April 1 90-day forecasts

Approach	RPSc	RPSf	RPSS	AdjRPSc	AdjRPSf	AdjRPSS
Max						
1	1.089	1.214	-11.5	2.231	2.000	10.4
2	1.089	1.118	-2.6	2.231	1.946	12.8
3	1.089	1.176	-7.9	2.231	2.090	6.3
Min						
1	1.089	3.000	-175.4			
2	1.089	1.746	-60.3			
3	1.089	2.368	-117.4			
Volume						
1	1.089	1.657	-52.1	2.231	2.250	-0.8
2	1.089	1.055	3.2	2.231	1.789	19.8
3	1.089	1.048	3.8	2.231	1.840	17.5

FTDC2 July 1 90-day forecasts

Approach	RPSc	RPSf	RPSS	AdjRPSc	AdjRPSf	AdjRPSS
Max						
1	1.089	0.616	43.4	2.232	0.902	59.6
2	1.089	0.636	41.6	2.232	0.949	57.5
3	1.089	0.699	35.8	2.232	0.902	59.6
Min						
1	1.088	2.822	-159.4			
2	1.088	0.799	26.5			
3	1.088	2.694	-147.6			
Volume						
1	1.089	0.819	24.8	2.231	1.051	52.9
2	1.089	0.595	45.3	2.231	0.965	56.8
3	1.089	0.660	39.4	2.231	0.809	63.8

POUC2 April 1 90-day forecasts

Approach	RPSc	RPSf	RPSS	AdjRPSc	AdjRPSf	AdjRPSS
Max						
1	1.089	1.801	-65.3	2.230	2.222	0.3
2	1.089	1.021	6.3	2.230	1.793	19.6
3	1.089	1.003	7.9	2.230	1.824	18.2
Min						
1	1.117	3.062	-174.3			
2	1.117	2.275	-103.7			
3	1.117	1.531	-37.1			
Volume						
1	1.089	2.746	-152.1	2.231	2.879	-29.0
2	1.089	1.155	-6.0	2.231	1.961	12.1
3	1.089	1.095	-0.5	2.231	1.789	19.8

POUC2 July 1 90-day forecasts

Approach	RPSc	RPSf	RPSS	AdjRPSc	AdjRPSf	AdjRPSS
Max						
1	1.089	1.948	-78.8	2.231	2.109	5.5
2	1.089	0.844	22.5	2.231	1.640	26.5
3	1.089	1.108	-1.7	2.231	1.401	37.2
Min						
1	1.088	3.000	-175.6			
2	1.089	1.758	-61.3			
3	1.088	1.681	-54.4			
Volume						
1	1.089	2.855	-162.1	2.231	2.887	-29.4
2	1.089	0.833	23.5	2.231	1.687	24.4
3	1.089	1.252	-14.9	2.231	1.542	30.9

GRPC2 April 1 90-day forecasts

Approach	RPSc	RPSf	RPSS	AdjRPSc	AdjRPSf	AdjRPSS
Max						
1	1.089	2.141	-96.5	2.232	2.441	-9.4
2	1.089	1.108	-1.7	2.232	1.949	12.7
3	1.089	1.038	4.8	2.232	1.922	13.9
Min						
1	1.102	2.938	-166.5			
2	1.102	2.166	-96.5			
3	1.102	2.019	-83.2			
Volume						
1	1.089	2.755	-153.0	2.231	2.883	-29.2
2	1.089	1.244	-14.2	2.231	2.004	10.2
3	1.089	1.146	-5.3	2.231	1.890	15.3

GRPC2 July 1 90-day forecasts

Approach	RPSc	RPSf	RPSS	AdjRPSc	AdjRPSf	AdjRPSS
Max						
1	1.089	2.291	-110.3	2.230	2.398	-7.5
2	1.089	1.108	-1.7	2.230	1.860	16.6
3	1.089	1.067	2.0	2.230	1.839	17.5
Min						
1	1.089	3.000	-175.4			
2	1.088	2.025	-86.0			
3	1.089	1.299	-19.3			
Volume						
1	1.089	2.931	-169.1	2.231	2.941	-31.8
2	1.089	0.971	10.9	2.231	1.953	12.5
3	1.089	1.368	-25.6	2.231	2.058	7.8

The RPSS statistics can be sensitive to the selection of bins, particularly with smaller sample sizes. The statistics in ***Table 7-3*** were computed using seven bins, evenly distributing the bins over the flow range based on the percentage of historic flows in each bin. In ***Table 7-4***, RPSS statistics computed using 3, 5, and 7 bins are presented. The 3-bin statistics were computed by breaking the historic flow distribution into 35%, 30%, and 35% bins, and the 5-bin statistics were computed by breaking the historic flow distribution into equal percentages. The results show that for some variables, the bin selection significantly affects the resulting statistics. All subsequent analyses that are presented use 7 bins and should be compared with ***Table 7-3***

Table 7-4. Comparison of RPSS and adjusted RPSS statistics computed using 3, 5, and 7 bins

FTDC2 April 1 90-day forecasts

Approach	3bin RPSS	5bin RPSS	7bin RPSS	3bin ARPSS	5bin ARPSS	7bin ARPSS
Max						
1	-12.4	-16.3	-11.5	10.1	9.5	10.4
2	-2.0	-6.7	-2.6	14.7	12.2	12.8
3	-2.5	-10.0	-7.9	13.3	6.5	6.3
Min						
1	-132.5	-158.1	-175.4			
2	-33.2	-45.9	-60.3			
3	-97.7	-102.4	-117.4			
Volume						
1	-44.4	-52.8	-52.1	1.2	0.0	-0.8
2	8.8	1.8	3.2	22.8	20.6	19.8
3	5.1	4.8	3.8	18.6	19.4	17.5

FTDC2 July 1 90-day forecasts

Approach	3bin RPSS	5bin RPSS	7bin RPSS	3bin ARPSS	5bin ARPSS	7bin ARPSS
Max						
1	9.7	44.3	43.4	38.7	59.1	59.6
2	27.5	48.8	41.6	46.9	58.3	57.5
3	18.3	22.7	35.8	48.3	53.1	59.6
Min						
1	-129.3	-150.8	-159.4			
2	35.0	29.2	26.5			
3	-118.1	-129.9	-147.6			
Volume						
1	25.0	18.3	24.8	51.2	47.9	52.9
2	37.1	33.3	45.3	50.3	49.7	56.8
3	8.9	23.1	39.4	49.4	54.6	63.8

POUC2 April 1 90-day forecasts

Approach	3bin RPSS	5bin RPSS	7bin RPSS	3bin ARPSS	5bin ARPSS	7bin ARPSS
Max						
1	-49.0	-71.7	-65.3	2.3	-3.4	0.3
2	-6.8	10.3	6.3	16.5	20.4	19.6
3	3.5	8.8	7.9	18.8	17.7	18.2
Min						
1	-132.6	-163.9	-174.3			
2	-86.8	-114.5	-103.7			
3	-59.0	-72.2	-37.1			
Volume						
1	-130.9	-143.0	-152.1	-17.6	-24.5	-29.0
2	-7.9	-9.1	-6.0	10.9	11.7	12.1
3	-0.2	-5.4	-0.5	19.2	18.1	19.8

POUC2 July 1 90-day forecasts

Approach	3bin RPSS	5bin RPSS	7bin RPSS	3bin ARPSS	5bin ARPSS	7bin ARPSS
Max						
1	-22.5	-79.0	-78.8	28.0	7.2	5.5
2	40.4	11.2	22.5	39.5	21.1	26.5
3	-6.2	-17.0	-1.7	33.1	31.6	37.2
Min						
1	-108.6	-158.0	-175.6			
2	-56.2	-66.8	-61.3			
3	-52.3	-84.8	-54.4			
Volume						
1	-130.9	-150.3	-162.1	-16.6	-23.8	-29.4
2	36.8	25.8	23.5	33.7	26.6	24.4
3	-10.0	3.3	-14.9	37.9	39.0	30.9

GRPC2 April 1 90-day forecasts

Approach	3bin RPSS	5bin RPSS	7bin RPSS	3bin ARPSS	5bin ARPSS	7bin ARPSS
Max						
1	-94.6	-104.5	-96.5	-11.0	-14.3	-9.4
2	4.5	-4.1	-1.7	17.3	9.0	12.7
3	6.1	4.8	4.8	17.8	13.7	13.9
Min						
1	-132.5	-156.2	-166.5			
2	-64.7	-93.9	-96.5			
3	-70.3	-69.5	-83.2			
Volume						
1	-132.5	-154.6	-153.0	-17.9	-26.7	-29.2
2	-10.9	-18.0	-14.2	11.6	9.0	10.2
3	2.8	-15.1	-5.3	17.1	10.5	15.3

GRPC2 July 1 90-day forecasts

Approach	3bin RPSS	5bin RPSS	7bin RPSS	3bin ARPSS	5bin ARPSS	7bin ARPSS
Max						
1	-105.4	-113.7	-110.3	-6.6	-10.3	-7.5
2	9.5	-22.6	-1.7	21.9	8.5	16.6
3	2.4	-2.4	2.0	23.3	16.7	17.5
Min						
1	-132.6	-158.1	-175.4			
2	-36.4	-48.5	-86.0			
3	-45.4	-24.0	-19.3			
Volume						
1	-132.6	-152.5	-169.1	-17.6	-25.2	-31.8
2	15.2	17.9	10.9	16.4	17.2	12.5
3	-14.9	-20.9	-25.6	14.1	10.6	7.8

To better understand the sensitivity of RPS and RPSS to years with outlying data, the April 1, 90-day volume statistics were re-calculated excluding the forecast from 1995, which was an anomalous year with a particularly dry spring and an unusually wet summer, such that resulting flows were much higher than would have been forecast in the spring. The results for RPS and RPSS are shown in ***Table 7-5*** and compared with RPSS with 1995 included. The results for ARPS and ARPSS are shown in ***Table 7-6***. A review of these tables indicates several interesting results. First, as expected, the overall RPSS increases significantly, suggesting that anomalous data have significant weight in calculation of RPS. Secondly, although the ARPSS increases as well, it typically does not increase as dramatically as RPSS, which is also to be expected, since the ARPS is less sensitive to anomalous data. Having noted this, it also should be mentioned that the anomalous data are in fact drawn from the true distribution of historical events and cannot be ignored in considering future probabilities of streamflow forecasts and forecast reliability.

Table 7-5. Comparison of RPSS statistics computed including and excluding 1995 data

Location	Approach	Original RPSS	Excluding 1995			Change in RPSS
			RPSc	RPSf	RPSS	
FTDC2	1	-52.1	1.086	1.613	-48.6	3.5
	2	3.2	1.086	0.846	22.1	18.9
	3	3.8	1.086	0.847	22.0	18.2
POUC2	1	-152.1	1.038	2.885	-178.0	-25.8
	2	-6.0	1.038	0.950	8.5	14.5
	3	-0.5	1.038	0.878	15.4	15.9
GRPC2	1	-153.0	1.038	2.895	-178.9	-26.0
	2	-14.2	1.038	1.104	-6.4	7.8
	3	-5.3	1.038	0.972	6.3	11.6

Table 7-6. Comparison of adjusted RPSS statistics computed including and excluding 1995 data

Location	Approach	Original ARPSS	Excluding 1995			Change in ARPSS
			ARPSc	ARPSf	ARPSS	
FTDC2	1	-0.8	2.228	2.188	1.8	2.6
	2	19.8	2.228	1.604	28.0	8.2
	3	17.5	2.228	1.662	25.4	7.8
POUC2	1	-29.0	2.180	3.013	-38.2	-9.2
	2	12.1	2.180	1.758	19.3	7.2
	3	19.8	2.180	1.571	28.0	8.1
GRPC2	1	-29.2	2.180	3.021	-38.6	-9.4
	2	10.2	2.180	1.846	15.3	5.1
	3	15.3	2.180	1.708	21.6	6.4

Another important observation that can be made from the RPS statistics and the underlying annual forecasts is that forecasts of the minimum flow during a 90-day period are rarely accurate. Analysis of the traces and the observed data indicate that the reason for this is that the observed flow during the low flow portions of the periods analyzed typically fluctuate widely as a percent of total flow, and often drop to at or near zero flow for a single day at some locations, perhaps as a result of the abrupt nature of some regulation operations. The regulation models that have been developed aim to represent the trends in regulation and their variation from year to year, and do not include any capability to represent instantaneous fluctuations that result from the timing of regulation operations when, for example, exchanges are made and a short interval of low flows result. Because of this difficulty with the minimum flow observation, no further analyses were performed using the minimum flow forecast beyond the tabulation of RPS and RPSS statistics. An analysis of a 7-day minimum flow might provide more meaningful statistics to evaluate.

After reviewing the foregoing, additional questions remained about the sources of uncertainty and the quality of the forecasts. Using the same ESP verification files, statistics were prepared for two additional cases to provide more information. The first case was the July 1, 30-day volume, computed only for Approach 3. This case was intended to indicate if improved skill and discrimination could be obtained by reducing the effect of climatological variability using a shorter forecast window and beginning when initial conditions are thought to have a significant impact. An April 1 start date was considered, but inspection of traces indicated that although the seasonal snow-pack is well established by this time, little melt occurs in April and there is little variability in streamflow, so that little discrimination may be visible in the April 1, 30-day forecast. The standard and adjusted RPSS statistics for the 30-day July 1 volume forecast are compared with 90-day forecast in ***Table 7-7***.

Table 7-7. Comparison of 90- and 30-day July 1 total volume forecast RPSS and adjusted RPSS

Location	90-day RPSS	30-day RPSS	90-day ARPSS	30-day ARPSS
FTDC2	39.4	38.2	63.8	65.0
POUC2	-14.9	-3.4	30.9	39.4
GRPC2	-25.6	6.5	7.8	40.8

These results show significant improvement in both standard and adjusted RPSS, due in part to the factors noted above, for POUC2 and GRPC2. However, at FTDC2, there is little improvement going from a 90-day to a 30-day forecast window. This may indicate that for FTDC2, the 90-day forecasts of flow volume are relatively good, and little improvement can be made moving to a shorter forecast window. The POUC2 and GRPC2 flow volume forecasts, however, are less accurate due to the large amount of regulation. The climate variability also may be more pronounced in the plains than in the mountains in the summer months due to convective thunderstorm activity. By moving to a 30-day forecast window at these two locations, the forecast skill is therefore significantly improved. This suggests the importance of evaluating statistics at different times of the year and at a variety of time scales.

The second additional case involved using the long-term output from Approach 3 as if it were the observed regulations. This is roughly equivalent to assuming perfect hydrologic and regulation models, such that the only source of variability is the climate (this is not strictly true, since the result has been to alter the observations to reflect the simulation, and not to perfect the simulation itself). It represents the upper limit on potential forecast skill that can be achieved solely through hydrologic modeling (i.e. without using climate forecasts in place of the historical climate). For this case the April 1 and July 1, 90-day maximum flows and volumes at FTDC2 were evaluated. The standard and adjusted RPSS statistics for this case are shown in ***Table 7-8*** below (Perfect model) and are compared with the RPSS statistics as previously computed (Actual model, from ***Table 7-3*** above).

Table 7-8. Comparison of 90-day FTDC2 "Perfect" and Actual models

Date	Variable	Perfect model		Actual model	
		RPSS	ARPSS	RPSS	ARPSS
April 1	Max Daily Flow	8.5	16.8	-7.9	6.3
	Total Volume	29.3	32.7	3.8	17.5
July 1	Max Daily Flow	85.5	84.0	35.8	59.6
	Total Volume	89.7	85.7	39.4	63.8

These results indicate that for April 1 forecasts, although significant improvement theoretically may be achieved through more accurate modeling, uncertainty associated with climate variability appears to be limiting forecast skill to a greater extent. In the July 1 forecast, information in the initial hydrologic conditions and the actual model provide for a significant improvement in the forecasts. However, model improvements provide the potential for even better forecasts. In the case of the July 1 forecasts, the climate uncertainty is less because of the reduced climate variability over the 90-day period.

Finally, for some cases, a subjective evaluation of forecast skill appeared to indicate value in the forecast, yet this was not reflected in the resulting RPS and RPSS statistics. An example RPSS output file (*.iwk file) for such a case is included in ***Appendix C*** for the POUC2 July 1, 90-day volume forecast.

7.2.2 Reliability

Reliability provides information about the conditional distribution of observations given the forecasts (p(o|f)). Reliability indicates how often different observations have occurred when a particular forecast was given (Murphy and Winkler, 1987).

In an analysis of reliability, the flow range is separated into discrete bins. For instance, ***Figure 7-1*** shows the reliability plots for two scenarios. In each scenario, the flow range is separated into a low, mid, and high range. The reliability is calculated by examining the probability assigned to each possible flow category for each ESP run and counting the number of observations that occur in that category when it was predicted at the given probability level.

If the forecasts are perfectly reliable, then (p(o|f)) = 1, and the values of the frequency of observations versus forecast probability will plot along the 1:1 line on a reliability diagram (Wilks, 1995). When a forecast is reliable, when a given flow level is predicted with a low probability, that flow level actually occurs with a low frequency. Conversely, when a given flow level is predicted with a high probability, that flow level occurs with a high frequency. Forecasts that are not as reliable will not plot along the 1:1 line. In ***Figure 7-1***, the plot on the left (generated from the ESPVS analysis of the Approach 2, April 1 maximum flow forecasts for GRPC2) shows relatively high forecast reliability at all three flow levels. The plot on the right (generated from the ESPVS analysis of the Approach 1, April 1 maximum flow forecasts for FTDC2) shows good forecast reliability at low flows, but poorer reliability at medium and high flows. In the left plot, the forecast reliability for low flows is better than for high flows. Finally, forecasts that are biased towards over- or under-forecasting will plot on either side of the 1:1 line. For instance, in the left plot, high flows are predicted with a lower probability than the frequency of which they actually occur.

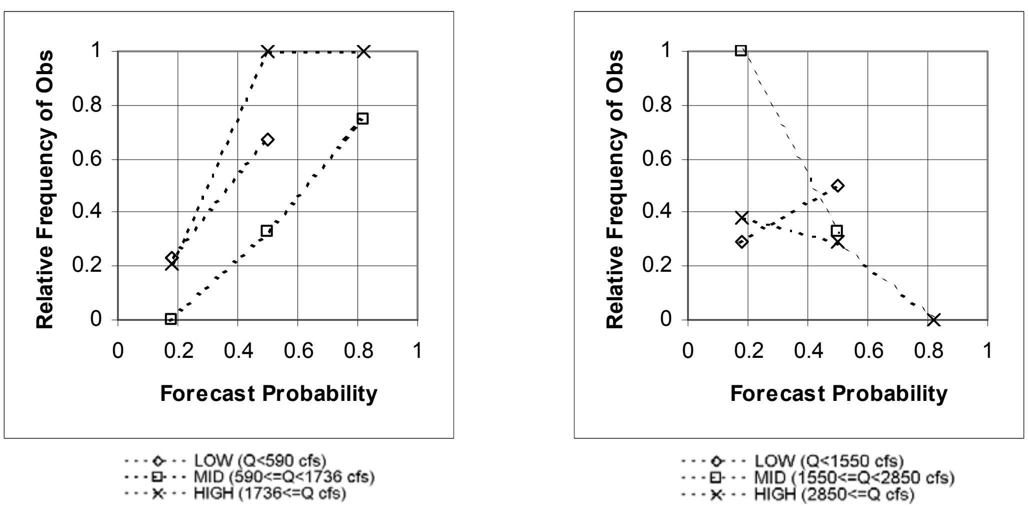


Figure 7-1. Comparison of good and bad reliability plots

Reliability plots were generated for each of the three approaches for the April 1 and July 1 forecasts at each of the three verification points (FTDC2, POUC2, and GRPC2) for maximum daily flows and total flow volumes. This resulted in 36 reliability plots, which can be found in ***Appendix D***. Each figure in the appendix is followed by a table that includes the data used in the plot.

7.2.2.1 Interpretation of the 90-day Reliability Plots

The following general observations concerning the reliability plots can be made:

- Approach 1 does not account for any regulation effects. This resulted in oversimulation of flows during the calibration when compared to the observed flows (***Table 5-2***). This is also reflected in the reliability plots for the POUC2 and GRPC2 total flow volumes (***Figure D-5*** and ***Figure D-6***). In each of these plots, there is only a single data point for each flow level. High flows are always predicted with a high probability, and low and middle range flows are always predicted with a low probability. Because the regulation effects are not as pronounced at FTDC2, there are additional points on these reliability plots for Approach 1 (***Figure D-4***).
- Care must be taken when interpreting the reliability plots. The results are influenced by the number of data points. For instance, the July 1 reliability plot for Approach 2 total flow volumes at FTDC2 initially appears to have poor reliability for low and mid-range volumes (***Figure D-5***). However, this is a result of the number of forecasts in each range. When the data used to create the plot were investigated (***Table D-5b***), there was only a single year in which low or mid-range volumes were predicted with a mid-range forecast probability. With only a single forecast in the middle probability range, in order to generate perfect reliability associated with the forecast, there would need to be half of an observation in the middle flow range. Therefore, since there either was or was not an observation in the middle flow range, the values plot with a relative frequency of observation of one or zero on the reliability plot, causing the reliability to look bad in either case. In this scenario, the underlying data causes the reliability plot to look worse than it actually is.
- Considering the previous points, Approaches 2 and 3 generally appear more reliable than Approach 1, as expected, particularly with respect to flow volumes.
- Approaches 2 and 3 appear to demonstrate relatively good reliability for both maximum daily flows and flow volumes for all flow levels at each location in the July 1 forecast. There are some exceptions, such as the mid-range flow volume at GRPC2 for Approach 3 (***Figure D-6***). Again, numerous plots are affected by the sparse number of forecasts with mid-range probability that show up as either a zero or one relative frequency of observations.
- The reliability of the July 1 forecasts generally appears to be better than the reliability of the April 1 forecasts. The April 1 total volume forecasts using Approaches 2 and 3 demonstrate good reliability at FTDC2 (***Figure D-4***), and slightly poorer reliability for some flow ranges at POUC2 and GRPC2.
- The reliability of the maximum flow forecasts generally does not appear to be as good as the flow volume forecast reliability.

7.2.2.2 Additional Reliability Analyses

The reliability statistics of two additional scenarios were investigated corresponding to the additional scenarios analyzed for the RPSS statistic. In the first, the July 1, 30-day Volume for Approach 3 was evaluated at each verification location. The reliability plots for these cases are presented in ***Figure D-7***, and can be compared to the corresponding reliability plots for the 90-day forecast.

The July 1 90-day volume reliability plots yielded good results for each location at every flow range for Approach 3, with the exception of mid-ranged flows at GRPC2. It appears that the reliability is poorer for the 30-day forecast for at least one flow range at every location. However, this is most likely a result of the high reliability associated with the 90-day forecasts, and potentially the influence of a few data points that did not hurt the reliability of the 90-day forecasts but do reduce the reliability of the 30-day forecasts in minor ways. In reality, the small data set utilized to generate the reliability plots renders the differences between the reliability of the 30- and 90-day forecasts inconclusive.

The second additional scenario involved the reliability of the forecasts when the historic simulation is used as observed data. This represents the case of a "perfect" simulation, as described above for the RPSS statistic, and represents the upper limit of forecast capability. The reliability is plotted for Approach 3 at FTDC2 for the April 1 and July 1 90-day maximum flow and total flow volume forecasts (***Figure D-8***). As expected, each variable demonstrates good reliability.

7.2.3 Discrimination

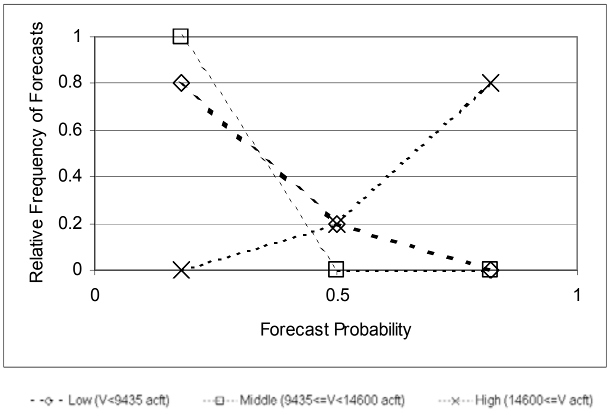
Discrimination expresses the conditional distribution of the forecasts given the observations (*(p(f|o)*). Discrimination reveals how often a particular forecast was given before an observation (Murphy and Winkler, 1987). For example, the forecasts perfectly discriminate for low flows if they assigned 100% probability to low flows before all the instances when low flows were observed. If however, the forecasts tended to give 100% chance to high flows as often as they gave 100% chance to low flows, the forecasts are considered to have poor discrimination with respect to low flows.

Discrimination is calculated by first separating the forecasts into groups according to the observation that occurred after the forecast was made. For each group, the frequency at which the various probability values are assigned to each possible observation is determined. Discrimination is useful for assessing the ability of the forecasts to distinguish between the likelihood of one observation versus another (Franz and Sorooshian, 2002).

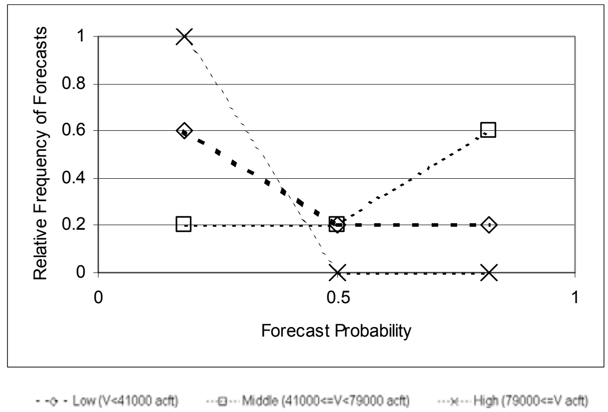
Figure 7-2 shows two different examples of discrimination plots. The plots are interpreted relative to the flow level that is being interpreted. For instance, the left plot shows the high flow discrimination for the ESPVS analysis of Approach 2 for the July 1 forecast of total volume at GRPC2. This is an example of good discrimination at all flow levels. Before the occurrence of high flows, high flows were predicted with a high forecast probability 80% of the time, a middle forecast probability 20% of the time, and with a low forecast probability 0% of the time. In addition, before the occurrence of high flows, low and mid-range flows were forecasted at a low probability a large number of times.

The right plot demonstrates the low flow discrimination from the ESPVS analysis of Approach 2 for the July 1 forecast of FTDC2 flow volumes. Before the occurrence of low flow volumes, low flows were predicted with a high probability only 20% of the time, but were given a low probability in the forecast 80% of the time. In addition, before the occurrence of low flow volumes, mid-range flow volumes were forecasted with a high probability a relatively high number of times. In this plot, when low flow volumes occurred, there is good high flow volume discrimination, as indicated by the low probability consistently assigned to high flows whenever low flows occurred.

The discrimination and reliability results are influenced by the limited sample size of observations. The ESPVS analysis was limited to a 16-year period. This was split into 3 bins, placing 5 or 6 observations into each bin. Therefore, each plot of discrimination is based on a sample size of 5 or 6 data points. As a result, an outlying value would significantly influence the resulting discrimination plots. If the flow range were split into a greater number of bins, the number of data points in each bin would be even less, resulting in less meaningful results.



High flow discrimination



Low flow discrimination

Figure 7-2. Comparison of good and bad discrimination plots

Discrimination plots were generated for three flow levels for each of the three approaches for the April 1 and July 1 forecasts at each of the three verification points (FTDC2, POUC2, and GRPC2) for both maximum daily flow and total flow volume, producing a total of 108 plots. The discrimination plots can be found in ***Appendix E***.

The discrimination plots for every flow level should be taken into consideration when analyzing the forecast discrimination ability at a location. For instance, the high flow discrimination plot for GRPC2 shows perfect discrimination for high, middle, and low flow levels for Approach 1 on July 1 (***Figure E-12***). However, this is because Approach 1 will always predict high flows at GRPC2, regardless of the initial conditions, because the approach does not account for diversions. Looking at the middle and low flow range plots for Approach 1, the plots look almost identical to the high flow plot. Therefore, the fact that Approach 1 discriminates well for high flows when high flows occur is not significant since high flows are always forecasted.

7.2.3.1 Interpretation of 90-day Discrimination Plots

The following general observations concerning the discrimination plots can be made:

- None of the three approaches shows good discrimination at every flow level for the maximum daily flow for April 1 at any of the three locations. Although some of the discrimination plots show good results for each flow category (e.g. Approaches 2 and 3 for POUC2 in the middle flow range, ***Figure E-3***), there is not good discrimination of all flow categories for the other flow ranges. Although none of the approaches has good discrimination of all flow levels for maximum daily flows on April 1, Approaches 2 and 3 do generally better discriminate than Approach 1 for this variable on this date.

- For the maximum daily flow on July 1 at FTDC2 (***Figure E-2***), Approaches 2 and 3 show relatively good discrimination for each flow level when high and low flows occur, although when mid-range flows occurred, neither approach discriminated that well. Both approaches appear to have better discrimination than Approach 1. For the maximum daily flow on July 1 at POUC2 and GRPC2, Approaches 2 and 3 show relatively good discrimination for every flow level when mid-range flows occurred, but varied discrimination ability when high or low flow maximums occur.

- No regulation modeling is computed for Approach 1. The results of this can be seen in the discrimination plots for the predicted total flow volumes for Approach 1. At POUC2 and GRPC2, each of the sets of discrimination plots (April 1 and July 1) look identical for Approach 1 because high flows are always predicted (diversions from the river are unaccounted for). However, there is less regulation that occurs above FTDC2, so the discrimination abilities of Approach 1 are better at this location. Approach 1 actually has the best discrimination of the three approaches at every flow level for April 1 at FTDC2 when high flows occur (***Figure E-7***). However, the other approaches better discriminate for the other cases.

- For the April 1 flow volume, none of the three approaches show good discrimination at all flow levels for a given flow volume range.

- For the July 1 flow volume, the results were varied. At FTDC2, Approaches 2 and 3 show good discrimination at every flow level when mid-range flow volumes occurred, but varied discrimination when low or high flow volumes occurred.

- In comparing the discrimination abilities of Approaches 2 and 3, one does not provide clearly superior discriminating abilities than the other. The discrimination plots for flow volumes at FTDC2 for both April 1 and July 1 are almost identical for both approaches. At other locations, one approach provided better discrimination than the other when one flow volume would occur, but the other approach would better discriminate for a different flow volume. In ***Figure E-10***, the total volume forecast at POUC2 on July 1, Approach 2 shows good discrimination of all flow levels when high flows occurred, and relatively good discrimination at all flow levels when low flows occurred. However, the discrimination when mid-range flows occurred is not as good. Approach 3 yielded good discrimination of all flow levels when mid-range flows occurred but not as good discrimination when low or high flow volumes occurred. In ***Figure E-12***, the total volume forecast at GRPC2 on July 1, Approach 2 shows better discrimination results when high flows occurred than Approach 3, but Approach 3 has better discrimination results when low flow occurred.

- Generally, it appears that Approaches 2 and 3 yielded better discrimination of total flow volumes than maximum daily flows, and the July 1 forecasts resulted in better discrimination than the April 1 forecasts for both the total flow volume and maximum daily flow.

7.2.3.2 Additional Discrimination Analyses

The discrimination statistics for two additional scenarios were investigated corresponding to the additional scenarios analyzed for the RPSS and reliability statistics. In the first, the July 1, 30-day volume for Approach 3 was evaluated at each verification location. The discrimination plots for these cases are presented in ***Figure E-13***, and can be compared to the corresponding discrimination plots for the 90-day forecast.

The discrimination results for the 30-day forecasts follow similar trends to those of the reliability relative to the 90-day forecasts. It appears that for most variables, the models demonstrate similar discrimination. Although there are minor differences between the discrimination of different variables, the differences appear to be due to the small data set utilized for verification. One interesting conclusion is that the resolution of the GRPC2 forecasts improves moving from a 90-day forecast window to a 30-day forecast window. If a forecast has high resolution, a given flow level will be predicted with either high or low probability, but rarely with a mid-range probability. In each of the 30-day discrimination plots for GRPC2, none of the variables was ever predicted with a mid-range probability, but for the 90-day discrimination plots for GRPC2, this was not the case. The resolution for the other two locations was already high for the 90-day forecasts.

The second additional scenario involved the discrimination of the forecasts when the historic simulation is used as observed data. This represents the case of a "perfect" simulation, as described above for the RPSS statistic, and represents the upper limit of forecast capability and the influence of climatological variability on forecast results. The discrimination is plotted for Approach 3 for the April 1 (***Figure E-14***) and July 1 (***Figure E-15***) 90-day maximum flow and total flow volume forecasts at FTDC2. As expected, the model demonstrates excellent discrimination at every flow level for every variable for the July 1 forecasts of both variables. The April 1 results did not follow the same trends, however. The model shows relatively poor discrimination of many variables on this date. These results correspond to the results for the RPSS statistic (***Table 7-8***), and are indicative of the higher variability in climatology on April 1 than on July 1. The results indicate the forecast skill is limited by climatological variability on April 1.

7.3 Evaluation of the Verification of Approaches

As previously noted, the purposes of this evaluation were to compare the performance of the three approaches in developing meaningful ESP forecasts, and to provide insight into the quality of the forecasts. Because of the nature of the regulation in the Poudre river basin and its tendency to produce large fluctuations during low flow periods that often reduce the flow to near zero, the regulation models are unable to accurately simulate or forecast the minimum daily flow over a 90-day period. As a result, the statistical measures show little forecast skill for the minimum daily flow in any of the approaches and there is little information in this forecast variable to compare approaches. A more appropriate variable for evaluating the capability of the models to forecast low flows might be the minimum weekly volume over a 30- or 90-day period. This variable was not analyzed, and minimum flows are not considered in the following evaluation.

7.3.1 Approach 1

When compared with the historical distribution, Approach 1 showed poor forecast skill for nearly all variables, dates, and locations. This was expected inasmuch as this approach neglects all regulation in the basin. The only exception seems to be the July 1, 90-day peak and volume at FTDC2, which may result because net regulation effects at the canyon gage at that time of the year are reduced. Part of the purpose of the analysis, however, was to identify the improvement that could be gained through regulation modeling. In this context, it seems clear that regulation modeling (Approaches 2 and 3) significantly improves forecast skill, and that if forecasts of regulated flow are to be provided, a forecast based on the historical distribution of flows would likely be better than one based on a natural flow simulation.

7.3.2 Approach 2

Approach 2 represents a significant improvement over Approach 1 in virtually all areas. It seems to perform nearly as well and in some cases better than Approach 3. An interesting result is that in several cases where it out-performs Approach 3 in RPSS, it under-performs in ARPSS. This may be because when the series of historical diversion time series are imposed on a variety of initial conditions in Approach 2 a smoother distribution of flows results than with full regulation modeling in Approach 3, such that fewer outlying forecasts result, although fewer forecasts predict correctly with high probability. One of the most important considerations in evaluating the use of historical diversions to model regulation in the Poudre River basin is that accurate and complete historical data were available for only 16 years. This limits a meaningful probabilistic forecast period using ESP to unacceptable levels. This approach, therefore, is useful for evaluation in relation to other approaches but may not be a real option for regulation modeling in the Poudre River basin.

A number of other considerations in evaluating this approach are as follows:

- In the verification analysis, historic, long-range ensemble forecasts are generated for every year. In each ensemble, one of the traces is based on the MAP and MAT time series for the current year being analyzed, and in the case of Approach 2, the observed aggregate regulation discharge time series for the current year. Therefore, for the trace of the current year, in Approach 2, the modeled regulation was perfect and the only variability was due to the hydrologic models. The same is not true for Approach 3, where only MAP and MAT time series are utilized. In ***Table 7-5***, the effects of poor simulations for a single year were demonstrated. Likewise, a single year with perfect regulation modeling could bias the Approach 2 statistics towards better results when compared with Approach 3. It may be preferable to perform a jackknife analysis and exclude the current year when generating historic ESP forecasts for ESP verification, although this capability is not built into the current version of ESPVS.
- In the Poudre River basin, initial conditions may have a minor effect on regulation from year to year, so that historical diversions may be tied more closely to climatology, especially over a 90-day period.
- Because regulation practices vary over time with changes in population and agriculture, historical diversions may not be appropriate representations of future diversions, even though they would tend to produce better verification statistics than a model representing current regulation.
- Likewise, a model representing current regulation may not verify well against historical diversions that have changed over time.

7.3.3 Approach 3

As with Approach 2, the regulation modeling in Approach 3 results in significant improvement over Approach 1, although the apparent improvement over Approach 2 is not as pronounced and may be questionable given the small sample (16 years) from which the results are drawn. Because of the limited number of years for which Approach 2 can be used, and considering the improvement in Approach 3 over Approach 1 and to a lesser extent over Approach 2, it would appear that Approach 3 is the preferred approach for generating ESP forecasts of regulated streamflow in the Poudre River basin. Questions that might arise, however, include the following: Does this approach represent a significant improvement over a forecast based on the historical distribution of observed streamflow? What guidance can be given to users regarding the degree of forecast skill found in various products at different times of the year? How do the sources of uncertainty in the forecast compare among the uncertainty in the climate, hydrologic models, and regulation models, among others?

The verification statistics begin to answer these questions. A review of the RPSS and ARPSS statistics for Approach 3 suggest that there may be significant forecast skill unless the decisions resting on the forecast are highly sensitive to infrequent wrong forecasts. The difference in discrimination found between the April 1 and July 1 forecasts and between 90-day and 30-day forecasts illustrate the variability in forecast confidence between dates and forecast variables. The comparison of verification statistics using the actual model versus the perfect model suggests that in April, the climate uncertainty is more prevalent, and in July, the model uncertainty predominates.

While the foregoing analysis may be sufficient for evaluation and comparison of regulation modeling approaches, additional analysis using a longer simulation period and comparing additional variables, forecast dates, and forecast windows would be required to respond to these questions more fully. Careful development and analysis of verification statistics could also provide guidance on further calibration efforts by identifying those forecast variables and time periods where performance is poor. For instance, the verification revealed that Approach 3 does a relatively poor job of forecasting maximum daily flows and total volumes at GRPC2 for the July 1 forecast. A bias in the forecasts was identified when the verification results were reviewed in detail. The calibration results were reviewed and the same bias was noted in the STAT-QME output. During the calibration, the large percent bias was considered satisfactory because the relative volumes were small. Initial attempts to remove the remaining bias revealed that it might be possible to improve the forecast for this period. If the forecast accuracy is considered insufficient for this location and time of year, the calibration could be revisited.

8.0 DISCUSSION AND RECOMMENDATIONS

Through the process of developing each of the three modeling approaches for the Poudre basin, a large amount of information was obtained and processed. The following summarizes the major conclusions and recommendations of the study.

8.1 Modeling Results and Approach Evaluation

The following sections compare the results of each modeling approach for the Poudre basin.

8.1.1 Development Effort

The first and second modeling approaches required much less effort for their development. There still was a fair amount of effort required to collect data and produce naturalized streamflow time series. After completion of the hydrologic model calibration for Approach 1, the second modeling approach required the aggregation of regulation time series, development of return flows, and addition of a few operations to add the appropriate time series together.

The third modeling approach built on the developments of the first two modeling approaches, but required significantly more effort than the first two modeling approaches. The level of development effort would vary for other basins based on the complexity of the streamflow regulation occurring in the basin.

8.1.2 Forecasting Accuracy

Approach 1 is limited to modeling the natural runoff in the Poudre River basin and as such does not model any regulation, and therefore performs poorly compared to observed streamflow. Its hydrologic models are, however, the basis for Approaches 2 and 3, and as a result, the accuracy of the hydrologic modeling components of all three approaches is the same. The hydrologic model accuracy is sometimes limited by the sparse network of precipitation and temperature stations.

Approach 2 incorporates historic net regulation time series, so that in a historic simulation mode it represents a near perfect simulation of regulation. In ESP verification, however, the historic regulation applied in some years does not always represent an appropriate response to the initial conditions.

Approach 3 uses model states and unfolding climatic conditions to simulate the complex regulations in the basin. Because of the difficulty of representing this complex system, accuracy is reduced from Approach 2 in the historic simulation mode, but because appropriate responses to varying initial conditions are incorporated into the simulation, accuracy in ESP verification may not be different than for Approach 2. The ability to generate ESP forecasts based on a larger sample set gives a significant advantage to Approach 3 compared to Approach 2 for long-range streamflow forecasts, even though the two approaches demonstrated similar forecasting skill for the limited analysis period.

8.1.3 Implementation Effort

In each modeling approach, stations, basin boundaries, MAT and MAP area definitions, segment topology, segment definitions, and other details needed to be changed to account for changes in the overall hydrologic modeling structure defined by MBRFC for this basin. Approach 2 required additional effort to define regulation time series and to account for those time series within the hydrologic model structure. Approach 3 required significant additional effort to properly define the segment topology and account for all flow components and time series interactions. In addition, significant effort was required to define time series plots to assist in real-time forecasting activities. If natural streamflow forecasts are desired using either Approach 2 or 3, the necessary information could be extracted from the currently defined system by adding a few additional operations. This would require minimal additional effort.

8.1.4 Ease of Real-Time Operations and Maintenance

Each of the three modeling approaches present a variety of challenges associated with real-time operations. Approach 1 has very simple segment definitions and therefore, from the standpoint of a forecaster unfamiliar with the Poudre basin, the modeling may be easier to understand. However, the accuracy of the streamflow forecasts using the first approach is very low in the lower sub-basins. Therefore, if Approach 1were implemented with no inclusion of operations to account for the regulation, particularly the diversion losses in the lower sub-basins, the model output would be relatively meaningless. The simulations would consistently have to be modified to attempt to capture the observed streamflow, and would require unreasonable modifications. Long-range streamflow predictions would have little value using Approach 1 because of the poor simulation capabilities of the system without modifications, although the long-range streamflow predictions using Approach 1, representing natural flow simulations, could be used to estimate potential water availability in the system, assuming no regulation, which may be of interest for water managers and water commissioners in making long-term decisions concerning their regulation practices.

Approach 2 also has simple segment definitions. A forecaster unfamiliar with the Poudre basin could easily understand what is occurring in each sub-basin and make modifications to the forecasts. Each segment contains a time series representing the net regulation in each sub-basin and the return flows in the lower sub-basins, so the inclusion of the effects of regulation could be accomplished relatively easily by entering in assumed observations of the net regulation and return flow for each sub-basin. The net regulation time series are configured to carry forward the latest observed data, so there would be some memory incorporated in the system, as long as the regulations did not rapidly change.

However, Approach 2 has no automatic forecasting capabilities for short-range streamflow forecasts. The regulation observations would be based on current streamflow observations at the outlet of each sub-basin, and the future simulations would assume no response of the regulations to changes in runoff throughout the basin. Streamflow forecasts would therefore rely heavily upon the experience and judgment of the forecaster in setting regulation levels in the sub-basins and interpreting the results. Although the use of historic observations of regulation conceptually could allow the capture of the effects of regulation in long-range forecasts, this study demonstrated that ESP verification results were rarely better, and usually not as good as full modeling of regulation. Therefore, the long-range forecasts could require as much interpretation and engineering judgment as those produced using Approach 1.

Approach 3 is significantly more complex than each of the previous two approaches, and therefore would be more challenging from the standpoint of system comprehension. An operational forecaster would be challenged to run the system with no previous experience and interpret the results, although significant effort was made to make the segment definitions as simple as possible and still capture the essential components of the flow. However, with time and familiarity the system would become more manageable. Although there are many possible manners of modifying the streamflow forecast at each location, with time the forecaster would better understand which components of the flow simulation may be causing a poor simulation at a given point. There would be situations in which inexperienced forecasters would be required to run the models, such as weekend, evening or holiday shifts. The complexity of the system should be considered in decisions concerning which approach is implemented.

There are advantages operationally to Approach 3 as well. The approach provides information concerning future regulation effects based on current model states, and therefore is not as reliant upon the interpretation and judgment of the forecaster. Each component of the flow may be modified to better capture the flow characteristics at the sub-basin outlets, yet the modifications will reflect both current and expected conditions in the basin. Long-range forecasts are at least as good and often better than Approach 2 and could be used with confidence.

Although each modeling approach has its benefits and shortcomings, it appears that over the long term, the third modeling approach might require less frequent adjustments than the alternate approaches. The approach may require less daily attention when it is tracking well with observations, although in reality the daily variations in regulations may necessitate fine-tuning on a regular basis, regardless of the approach. Although Approach 2 appears simpler to maintain, its operational use provides less information for making accurate streamflow predictions and relies upon the experience and judgment of the hydrologists.

8.1.5 Future System Modifications

In the event of changes to the water management practices in the Poudre basin, modifications could be made to the system to reflect these changes. In the first and second modeling approaches, no modifications would be made to segment definitions. In the second approach, the historic regulation time series used for long-range probabilistic forecasts would reflect the current practices less accurately, resulting in less accurate long-range streamflow forecasts. In the third modeling approach, the current segment definitions would have to be modified. This would require an intimate understanding of the current configuration and would involve revisiting the current model structure and determining appropriate ways to incorporate the changes to the system without disrupting the overall model structure. The third approach would involve some effort to incorporate changing water management practices, but the modeling accuracy would be maintained as well, as opposed to the alternate approaches. The model was developed so that components are related to regulation effects that they govern, allowing a tighter focus in reflecting any future changes in regulation practices in the system.

8.1.6 Analysis of Priorities and Needs

All of the above items need to be taken into consideration in making decisions concerning streamflow regulation modeling in other basins. The final decision concerning how to model regulation would be affected by a variety of factors, including funding, time and personnel availability for development and operations, basin size, magnitude of runoff generation, extent of regulation, potential costs in loss of infrastructure or lives, and users of forecast information.

In the case of the Poudre basin, each of the three approaches has been developed. Therefore, implementation effort is not a factor in deciding which of the three approaches to use. Approach 1 only produces natural flow forecasts. There are many users who could benefit from natural flow forecasts. However, it would not be difficult to extract the same information needed to produce natural flow forecasts from either Approach 2 or 3. Although Approach 3 is more complex and would require greater comprehension of the system than Approach 2, this approach could require less frequent adjustments to forecasts in real-time operations, would allow the use of a longer period of record for ESP forecast generation, and could be modified to capture significant changes in regulation practices in the basin for short-range and ESP forecasting.

8.2 ESPVS Recommendations

The ESP verification results highlighted the importance of forecast verification as a means of evaluating the overall quality of forecasts and for assessing the variability of forecast skill as a function of season, forecast window, location, and forecast variable. As probabilistic forecasts are developed and disseminated, additional verification studies may be appropriate. Of particular importance in expanding on the brief verification analysis performed as part of this task are the following considerations:

- Period of Record – the verification period used for this analysis was limited to 16 years due to the limited historical record of regulation data for Approach 2. Further analysis of Approach 3 could take advantage of additional historical MAP, MAT, and observed streamflow data that are available.

- Monthly Verification – All of the verification statistics evaluated are seen to vary as a function of the forecast date. Verification statistics could be prepared for each month of the year to enable the RFC to convey an estimate of forecast skill along with the probabilistic forecasts.

- Additional Variables – A thorough verification would include an analysis of statistics for all products that will be disseminated. In the case of minimum flow, it has been mentioned that a 7-day minimum flow might provide more meaningful statistics to evaluate.

- Additional Calibration – The forecast verification of specific variables can reveal problems in the forecasts of particular variables or months. This can indicate a need to improve calibrations based on the specific variables and times of year when long-range forecasts will be generated.

- ESPVS Development – The RES-J operation will need to be modified to work properly with the verification system. The changes made by RTi for this study will need to be incorporated into the NWS versions of the forecast system.

- Additional ESPVS Development – It may be preferable to perform a jackknife analysis and exclude the current year when generating historic ESP forecasts for ESP verification, although this capability is not built into the current version of ESPVS.

- ProbVS Development – ProbVS needs to be modified to properly write the dates that are submitted to ESPADP for analysis.

8.3 Recommendations for Future NWSRFS Enhancements

Throughout the course of the Poudre River modeling development, a wide range of operations was used to simulate a variety of flow components. The ease of development would have been improved if certain enhancements to NWSRFS were made. Although the Poudre River modeling provided another opportunity to exercise the limitations of NWSRFS modeling capabilities, the list of potential NWSRFS enhancements remained the same as those identified before the project. The following list includes items noted previously in the South Platte Implementation Plan – SPIP2.doc – delivered on April 30, 2004, under the heading NWSRFS Enhancements. The priorities are revised and ranked in order based on experience to date in modeling streamflow regulation in the Cache la Poudre River basin.

1. RES-J – modify the routines that manage carryover to allow RES-J to work properly in the ESP verification process. *Priority: High*

2. RES-J - A new method could be added to RES-J to compute release as a function of additional system variables, states, or time series value, similar to the capability found in LOOKUP3. *Priority: High*
3. RES-J - One or more methods could be developed to allow diversion from a node as a function of current flow at the node, consumptive use demand, or other model states. *Priority: High* (This capability could be developed and included in the new RES-J method noted above)
4. RES-J – Where multiple reservoirs are to be implemented using RES-J, it would be helpful to model all of the intermediate LAG-K models within the RES-J operation. This would require the RES-J LAG-K method to be modified to include the same capability as the LAG-K operation. (i.e. variable Lag) *Priority: High* (this item is taken from the National Strategies document – National Strategies2.doc – delivered on April 30, 2004, in the Appendix under the heading Potential enhancements to existing tools - RES-J. The priority is upgraded to *High*, although cost may preclude its inclusion with the other RES-J enhancements).
5. LOOKUP3 - The LOOKUP3 operation could be enhanced to allow a date to be specified as one of the independent variables. *Priority: High*
6. CONS_USE - Currently, return flows are assumed to return to the diversion point and are available for diversion. In many cases, return flows return well downstream of the diversion point, or even exit, the basin. Allowing the user to specify if the return flows are available for diversion would provide the user more flexibility in the use of the operation. *Priority: Moderate*
7. CONS_USE - An option could be included to have the operation compute return flows only, and to do so based on a given diversion time series. This would reflect situations where the actual diversion and subsequent return flow were limited by factors other than those currently considered in the operation. *Priority: Moderate*
8. Equation tool - A new operation could be added that would permit arithmetic operations to be performed on time series. It could follow the form $t = \mathrm{A}x + \mathrm{B}y + \mathrm{C}z + \mathrm{D}x^2 + \mathrm{E}y^2 + \mathrm{F}z^2 + \ldots$ where t is the output time series, x, y, and z are input time series, and A – F are constants. Additional terms could be added to include logarithms and inverses of time series values. *Priority: Moderate*
9. CONS_USE - Currently, the operation requires specification of an input streamflow time series from which the diversion will be withdrawn. Specification of the input time series could be optional to make it easier to simulate a case where the water source is a reservoir. *Priority: Low*
10. CONS_USE - An MAP input time series could be introduced to the operation and an accounting for the demand satisfied by precipitation could be added, or the consumptive use model could be coupled with a soil moisture accounting component. *Priority: Low*
11. CHANLOSS - The operation could be expanded to include an option to allow the computed loss or gain be a non-linear function of discharge. *Priority: Low* (this capability should be available as part of the LOOKUP-3 enhancement noted above).
12. CHANLOSS - This operation computes the resulting streamflow after the loss or gain is accounted for. It might be useful to generate a time series representing the actual gain or loss in addition to the resulting streamflow. *Priority: Low*
13. RES-J - A new method could be created that would make it easier to compute a reservoir release based on a consumptive use demand in a downstream part of the basin. *Priority: Low* (this capability should be satisfied by the first two items in this list)
14. RES-J - The rules capability could be enhanced to allow testing on additional variables, e.g., time series values and linear combinations of states. *Priority: Low*

8.3.1 Criteria

Because of the role that RTi plays as a developer and implementer of forecast system tools and forecast systems, our perspective is weighted more heavily toward additional modeling capability and less toward operational maintenance and ease-of-use. For example, RES-J performance speed does not appear in the list above because it does not provide additional capability as we see it, although in the end it could limit the overall utility of the model in operational use at RFCs. Likewise, items 1-6 in the list above add modeling capability, while items 7-13 add convenience in operations and maintenance. We hope that the perspectives of operational forecasters are taken into consideration before accepting the priorities that we have listed.

8.3.2 Functional Requirements

The ranking above lists specific proposed enhancements and not functional requirements or needed modeling capability. All but one of the items listed are taken from the South Platte Implementation Plan – SPIP2.doc. The section from which these items are taken also includes the general modeling needs that led to the recommendation of these specific enhancements. It may be useful to refer to that list of needs in evaluating the overall plan for the enhancements listed and ranked above. For example, rather than making a number of incremental changes to CONS-USE, it may be desirable to develop a new consumptive use operation based on a new design that takes into account the comments provided by RFCs and RTi during the course of this task.

8.4 Future Modeling Recommendations

The Cache la Poudre River basin was chosen as a test basin to evaluate modeling strategies and demonstrate the costs and benefits associated with modeling streamflow regulation in the South Platte watershed. The next phases will continue the development of streamflow regulation modeling in the South Platte. The following general recommendations are made for the continued development of streamflow regulation modeling in the South Platte and other basins.

8.4.1 Future Modeling Strategy

The Poudre River modeling development required three different modeling approaches to be developed for the system for verification comparisons and evaluation purposes. As a result of going through the formal process of developing each modeling approach, some important lessons were learned that could be applied to future modeling. Many of the particular methods of modeling specific components of water management in the Poudre basin could be used in future basins, although each basin has unique modeling challenges. However, the overall strategy of collecting all available regulation observations, developing natural flow time series for each forecast point, and aggregating regulations by sub-basin and by type provides a good means of isolating specific components of the flow for calibration. The development of natural flow time series provides a way to calibrate the hydrologic models without the complicating influence of regulation. The naturalized flow time series may then be used as observations of local runoff response to isolate the regulation effects in the basin without the additional noise associated with over or undersimulations of natural runoff. Finally, the specific aggregated regulation time series may be used to identify representative relationships between different regulations or management practices and hydrologic variables, such as relationships with natural runoff, consumptive use patterns, or accumulated precipitation over a period of time. The aggregated regulation time series provide an observed time series for the calibration of specific regulations.

Therefore, although the formal development of each modeling approach would not be completed in every basin, this systematic approach of implementation provides an effective means of developing appropriate models to represent streamflow regulation in a basin.

8.4.2 Future Implementation of the South Platte

The remainder of the South Platte watershed has significant streamflow regulation to supply the Colorado Front Range with water for municipal and agricultural purposes. RTi recommends the next phase focus on the basins located downstream of the Henderson forecast point (HNDC2) and upstream of the Kersey forecast point (KERC2), including the Big Thompson River, St. Vrain Creek, and Boulder Creek to the South of the Poudre and Lonetree Creek to the North. This would encompass all of the sub-basins outside the jurisdiction of Denver Water down to Kersey, although the transfer of some water from these rivers is controlled by Denver Water. Although there are many sub-basins upstream of the Henderson forecast point, the regulation in these sub-basins is very complex and involves a wide range of management practices. If the next phase focuses on the sub-basins between HNDC2 and KERC2, this would allow time for the development of additional NWSRFS enhancements that could be implemented in the sub-basins upstream of HNDC2 in a subsequent phase. It may be more desirable in the next phase to exclude those sub-basins controlled by Denver Water entirely and include some additional sub-basins upstream of the Henderson forecast point. This would involve excluding the South Fork of Boulder Creek and Ralston Creek, and including Clear Creek above Golden, Bear Creek above Morrison, Cherry Creek, and Plum Creek. Finally, after completing the calibration and implementation of all sub-basins upstream of KERC2, the lower reaches of the South Platte could be modeled in a final phase.

8.4.3 Enhancements to the Poudre System

The modeling configuration for the Poudre basin is complicated due to limitations in some of the NWSRFS operations. If certain NWSRFS enhancements are made to improve the capabilities for streamflow regulation modeling, it may be beneficial to revisit the Poudre River system in order to simplify the model configurations for maintenance and the understanding of forecasters. However, doing so would not necessarily improve the simulation capabilities for the river because alternative modeling methods were identified and implemented that worked around the NWSRFS limitations.

The quality of the regulation model calibration could be improved by computing and evaluating AHPS forecast product variables for both simulated and observed time series using ESPADP. RTi does not recommend this due to the amount of effort required that would be displaced from other regulation modeling activities.

The water management in the Poudre River and the rest of the South Platte is continuously evolving as the needs in the basin change. For instance, the cities of Fort Collins and Greeley recently announced plans to expand Halligan and Seaman reservoirs for municipal water supply. Over time, the model configuration may no longer reflect the current management practices in a broad sense, at which point the system would have to be revisited and the models revised.

9.0 CONCLUSIONS

In this task, three different modeling approaches were developed for the Cache la Poudre basin. In the first, hydrologic models were calibrated to simulate the unregulated basin runoff as a baseline to demonstrate the benefits of modeling regulation. In the second, historic time series of streamflow regulation were utilized to represent the effects of regulation on long-range streamflow forecasts. The final approach involved the development of simulation models to capture the effects of regulation in short and long-range streamflow forecasting. The third approach was deemed the most appropriate for regulation modeling in MBRFC's forecast system. It provides reasonable simulation accuracy, will permit the development of ESP forecasts using 25 or more years of historical data, and responds appropriately to both initial conditions and climate inputs for both short-term deterministic forecasting and for probabilistic forecasting using ESP.

Through the process, a systematic modeling approach was refined that can be applied in other basins to isolate regulation effects and develop appropriate modeling solutions. This approach is beneficial from a development standpoint, as well as potentially from a user standpoint. If the effects of regulation can be effectively separated from the natural hydrologic response for a basin, it may be beneficial to produce both natural and regulated long-range streamflow forecasts for the basin, particularly in locations that generate significant local runoff. Either of these forecasts may be of interest to different users making water management decisions based on a basin's potential water yield or the expected streamflow at a forecast point.

Verification of the three approaches for extended probabilistic forecasting confirmed the general effectiveness of the final regulation modeling approach, but raised questions about variations in forecast skill as a function of date, forecast variable, location, and forecast window. Additional verification analyses could further clarify the nature of the forecasts. During the verification analysis, the forecasting skill for minimum daily flows was shown to be poor due to the nature of regulations. A 7-day minimum flow forecast may be a more appropriate variable to forecast.

Enhancements to the forecast system to facilitate regulation modeling in the future were recommended. These enhancements will be beneficial in efforts to extend the regulation modeling in the Poudre River basin to include the remaining basins in the South Platte, beginning with South Platte tributaries between Henderson (HNDC2) and Kersey (KERC2), followed by the South Platte upstream of Henderson, and concluding with the lower reaches of the South Platte downstream of Kersey.

One of the primary purposes of this task was to compare and analyze the development effort required and the modeling capabilities resulting from implementing each of the three different regulation-modeling approaches. The effort documented in this report and the systematic comparison of modeling approaches presented here suggest that effective modeling of complex regulation is possible in NWSRFS, but that significant effort in data collection, analysis, model development, and calibration are required. Conditions in other regulated basins will vary as to the prominence of regulation effects, availability of regulation information and historical data, the effort required to characterize regulation, the significance of regulation model states, and seasonality of forecast skill, among others. Individual river forecast centers will need to work towards identifying appropriate methods to model streamflow regulation where it is a significant factor, considering potential improvements in short and long-range streamflow forecasts, implementation costs and benefits, and the subsequent benefits to end users of the streamflow forecasts.

10.0 REFERENCES

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APPENDIX A

Description of Plots and Time Series

Because of the complexity of the system, the plots are also complex. The following documentation describes the plots and time series found in the simCPlot/simCplot.best calibration deck. Discussion of how the time series were created refers to the simRES/simRES.curr calibration deck. All plots are created after scaling of time series to ensure proper display of English units. Plotted time steps are 6 hours.

PLOT-TS PLOT-EN2

Plot #1:

White—EHN_HI

Runoff from the EHNC2 basin above the EHNC2 pseudo-reservoir. The fraction of the total EHNC2 runoff from area below the reservoirs (EHN_LO) is subtracted from the total EHNC2 runoff. CHANLOSS EHN-P4 is used to scale the total EHNC2 runoff as a function of date to determine the lower runoff (EHN_LO).

Magenta—EHNR_R

Release from EHNC2 pseudo-reservoir. This is a calculated by RES-J using a SetRelease table plus uncontrolled spill.

Plot #2:

White—EHNIMPT

Import to the EHNC2 basin. Calibration demonstrated that this flow is best simulated by passing it directly through the EHNC2 pseudo-reservoir to be diverted in the POUC2 basin. Therefore, it is not simulated as part of EHNC2 pseudo-reservoir inflow.

Magenta—EHNR_W

Withdrawal from the EHNC2 pseudo-reservoir destined for Fort Collins water supply.

Plot #3:

White—EHNR_PE

EHNC2 pseudo-reservoir pool elevation as simulated by RES-J. Zero is empty. One-hundred is full, at which point the reservoir begins uncontrolled spill.

Magenta—PLNS_PE

Plains reservoir pool elevation as simulated by RES-J. Zero is empty. One-hundred is full. This was reviewed during calibration, but calibration to FTDC2 showed successful agreement to the point that EHNC2 pseudo-reservoir does not consider the Plains reservoir conditions in its operations.

Plot #4:

White—OBS_FTDQ

Observed historical flow at FTDC2 basin outlet (the Canyon Gage). Because no observations existed in the EHNC2 basin, the EHNC2 pseudo-reservoir was calibrated at FTDC2 following calibration of NCHC2 and SEAC2 basin regulation.

Magenta—FTDC2SIM

Simulated flow at FTDC2 basin outlet (the Canyon Gage).

PLOT-TS PLOT-NCH

Plot #1:

White—OBS_NCHQ

Observed (filled) historical flow at NCHC2 basin outlet. This filled time series was created through filling of time series with considerable missing periods. Also, observations at this point were only available for recent years. Regression techniques were used with observed downstream diversions and a gage below the diversion site to recreate this time series.

Magenta—NCHC2SIM

Simulated discharge at NCHC2 basin outlet, including water destined for diversion in the upper portion of SEAC2 (RES-J withdrawal) and uncontrolled spill (RES-J release) from the reservoir. (No controlled releases not destined for diversion occur in this calibration.)

Yellow—NCHRESIN

Simulated total inflow to the NCHC2 pseudo-reservoir. This is the sum of simulated imports to NCHC2 and simulated NCHC2 runoff.

Red—NCHR_R

Uncontrolled spill from NCHC2 pseudo-reservoir. (RES-J models this as release from the reservoir, maintaining it separate from the water planned for diversion downstream.)

Plot #2:

White—ONCHR_W

Observed diversions shortly downstream from the NCHC2 basin outlet. This time series contained large portions of missing data. Nevertheless, NCHC2 pseudo-reservoir was calibrated primarily to this time series.

Magenta—NCHR_W

Simulated withdrawals from the NCHC2 pseudo-reservoir. Physically, these enter the river downstream of the dam to be diverted from the river to the PLNS pseudo-reservoir shortly thereafter.

Plot #3:

White—NCHR_PE

Simulated NCHC2 pseudo-reservoir pool elevation. Zero is empty. One-hundred is full, at which point the reservoir begins uncontrolled spill. No observations were available for calibration.

Magenta—PLNS_PE

Plains reservoir pool elevation as simulated by RES-J. Zero is empty. One-hundred is full. This was reviewed during calibration, but NCHC2 pseudo-reservoir does not consider the Plains reservoir conditions in its operations.

Plot #4:

White—OBS_FTDQ

Observed historical flow at FTDC2 basin outlet (the Canyon Gage). Because limited observations existed in the NCHC2 basin outlet, discharge at FTDC2 basin outlet was considered during calibration.

Magenta—FTDC2SIM

Simulated flow at FTDC2 basin outlet (the Canyon Gage).

PLOT-TS PLOT-SEA

Plot #1:

White—OBS_SEAQ

Observed (filled) historical flow at SEAC2 basin outlet.

Magenta—SEAR_R

Simulated release from Seaman reservoir (SEAC2 basin outlet), including controlled release and uncontrolled spill from the reservoir.

Yellow—SEAR_R

Simulated total inflow to the Seaman reservoir. This is the sum of simulated local SEAC2 runoff and flow from upstream.

Plot #2:

White—SEAR_PE

Simulated Seam reservoir pool elevation. Zero is empty. One-hundred is full, at which point the reservoir begins uncontrolled spill. No observations were available for calibration.

Magenta—PLNS_PE

Plains reservoir pool elevation as simulated by RES-J. Zero is empty. One-hundred is full. This was reviewed during calibration, but SEAC2 pseudo-reservoir does not consider the Plains reservoir conditions in its operations.

Plot #3:

White—OBS_FTDQ

Observed historical flow at FTDC2 basin outlet (the Canyon Gage). Discharge at FTDC2 basin outlet was considered during calibration.

Magenta—FTDC2SIM

Simulated flow at FTDC2 basin outlet (the Canyon Gage).

PLOT-TS PLOT-FTD

Plot #1:

White—OBS_FTDQ

Observed historical flow at FTDC2 basin outlet (the Canyon Gage).

Magenta—FTDC2SIM

Simulated flow at FTDC2 basin outlet (the Canyon Gage).

Plot #2:

White—EHNIMPT

Import to the EHNC2 basin. Calibration demonstrated that this flow is best simulated by passing it directly through the EHNC2 pseudo-reservoir to be diverted in the POUC2 basin. This flow is a portion of the FTDC2 total flow.

Magenta—EHNR_R

Release from EHNC2 pseudo-reservoir. This flow is a portion of the FTDC2 total flow.

Yellow—SEAR_R

Simulated total inflow to the Seaman reservoir. This flow is a portion of the FTDC2 total flow.

Red—NCHR_R

Uncontrolled spill from NCHC2 pseudo-reservoir. While this is not directly a portion of FTDC2 total flow, it provides context of the NCHC2 pseudo-reservoir. This is non-zero only when NCHC2 pseudo-reservoir is full and spilling uncontrollably.

Green—FTD_NATR

The portion of the natural (unregulated) flow below EHNC2 pseudo-reservoir and Seaman reservoir that remains after a diversion occurs above FTDC2 outlet. This flow is a portion of the FTDC2 total flow.

Plot #3:

White—NATTFTD

Observed natural flow at FTDC2 basin outlet (the Canyon Gage).

Magenta—FTDSUM

Simulated natural flow at FTDC2 basin outlet (the Canyon Gage). Comparison of these two provides context into simulation error from hydrologic inputs as compared to regulation simulation errors.

PLOT-TS PLOT-PLS (Plains reservoir)

Plot #1:

White—PLNS_W

Simulate withdrawal from the PLNS pseudo-reservoir.

Magenta—PLNSCUK1

Simulated total demand on the PLNS reservoirs. This is a scaled estimate of consumptive use on the plains, given no supply limitations. (See WEIGH-TS PLNSCU02 and CHANLOSS PLNSCU02).

Yellow—PLNS_I

RES-J simulated total inflow to the PLNS pseudo-reservoir. This is the sum of diversions from FTDC2 and POUC2 basins (FTDDV2, POUDV1—see WEIGH-TS PLNSIN06) plus RES-J simulated flows for EHNC2 imports, diversions immediately downstream from NCHC2 basin outlet, and imports through HRST (Horsetooth) reservoir.

Red—PLNS_R

RES-J simulated excess water into the PLNS pseudo-reservoir. This uncontrolled spill represents error in simulation / parameterization of this deck best corrected through removal from the system.

Plot #2:

White—NCHR_W

Simulated withdrawals from the NCHC2 pseudo-reservoir. Physically, these enter the river downstream of the dam to be diverted from the river to the PLNS pseudo-reservoir shortly thereafter

Magenta—EHNIMPT

Import to the EHNC2 basin. Calibration demonstrated that this flow is best simulated in RES-J by passing it directly to the PLNS pseudo-reservoir.

Yellow—FTDDV1

Simulated diversion from natural flows above FTDC2 to the PLNS pseudo-reservoir.

Red—POUDV1

Simulated diversion from flows upstream of POUC2 basin outlet to the PLNS pseudo-reservoir. This does not include water from HRST (Horsetooth) reservoir, nor water imported through EHNC2 basin.

Green—HRSTR_R

Simulated release from HRST (Horsetooth) reservoir to the PLNS pseudo-reservoir.

Orange—PLNSSIMI

The sum of diversions from FTDC2 and POUC2 basins (FTDDV2, POUDV1—see WEIGH-TS PLNSIN06) to the PLNS pseudo reservoir.

Plot 3:

White—PLNS_PE

Plains reservoir pool elevation as simulated by RES-J. Zero is empty. One-hundred is full.

Plot 4:

White—OBS_POUQ

Observed discharge at POUC2 basin outlet (Fort Collins gage).

Magenta—POUC2SIM

Simulated discharge at POUC2 basin outlet (Fort Collins gage).

Yellow—OBS_FTDQ

Observed historical flow at FTDC2 basin outlet (the Canyon Gage).

Red—FTDC2SIM

Simulated flow at FTDC2 basin outlet (the Canyon Gage).

<u>PLOT-TS PLOTHRST</u> (Horsetooth pseudo-reservoir)
Plot #1:
White—QUOTA_R
Releases from the Quota reservoir to HRST pseudo-reservoir.

Plot #2:
White—HRSTR_R
Releases from the HRST pseudo-reservoir, representing imports through HRST (Horsetooth) reservoir for direct application to the PLNS pseudo-reservoir.

Plot #3:
White—QUOTA_PE
Simulated pool elevation for the Quota reservoir. The Quota reservoir is used to track total volume available from trans-basin import. Zero is empty. One-hundred is full.
Magenta—HRSTR_PE
Simulated pool elevation for the HRST pseudo-reservoir. Zero is empty. One-hundred is full.
Yellow—PLNS_PE
Plains reservoir pool elevation as simulated by RES-J. Zero is empty. One-hundred is full.

Plot #4:
White—PLNS_W
Simulate withdrawal from the PLNS pseudo-reservoir.
Magenta—PLNSCUK1
Simulated total demand on the PLNS reservoirs. This is a scaled estimate of consumptive use on the plains, given no supply limitations. (See WEIGH-TS PLNSCU02 and CHANLOSS PLNSCU02).
Yellow—PLNS_I
RES-J simulated total inflow to the PLNS pseudo-reservoir. This is the sum of diversions from FTDC2 and POUC2 basins (FTDDV2, POUDV1—see WEIGH-TS PLNSIN06) plus RES-J simulated flows for EHNC2 imports, diversions immediately downstream from NCHC2 basin outlet, and imports through HRST (Horsetooth) reservoir.
Red—PLNS_R
RES-J simulated excess water into the PLNS pseudo-reservoir. This uncontrolled spill represents error in simulation / parameterization of this deck best corrected through removal from the system.

PLOT-TS PLOT-POU

Plot #1:

White—OBS_POUQ
    Observed discharge at POUC2 basin outlet (Fort Collins gage).

Magenta—POUC2SIM
    Simulated discharge at POUC2 basin outlet (Fort Collins gage).

Yellow—OBS_FTDQ
    Observed historical flow at FTDC2 basin outlet (the Canyon Gage).

Red—FTDC2SIM
    Simulated flow at FTDC2 basin outlet (the Canyon Gage).

Plot #2: (See WEIGH-TS POUC2FN3, ADD/SUB POUC2FN8, and WEIGH-TS POUC2FN4)

White—FTDC2SIM
    Simulated flow at FTDC2 basin outlet (the Canyon Gage).

Magenta—POU_WTP
    Diversions from POUC2 basin for municipal supply.

Yellow—EHNIMPT
    Diversion from POUC2 basin reflecting water imported to EHNC2 and passed unregulated through EHNC2 and FTDC2 basins.

Red—POUDV1
    Diversion from POUC2 not reflected in POU_WTP, EHNIMPT nor HRST (Horsetooth) reservoir imports.

Green—POU
    Simulated local runoff from POUC2. Made available to satisfy POUDV1 requirements.

Orange—GWR_RPOU
    Groundwater returns above POUC2 basin outlet from PLNS reservoir water application

Plot #3:

White—POUFTDIN
    Simulated flows into POUC2 from FTDC2 basin that are not already earmarked for diversion. (WEIGH-TS POUC2FN1)

Magenta—POU
    Simulated local runoff from POUC2. Made available to satisfy POUDV1 requirements.

Yellow—GWR_RPOU
    Groundwater returns above POUC2 basin outlet from PLNS reservoir water application

Red—PLNS_R
    RES-J simulated excess water into the PLNS pseudo-reservoir. This uncontrolled spill represents error in simulation / parameterization of this deck best corrected through removal from the system.

Green—POU-WTP
    Diversions from POUC2 basin for municipal supply.

PLOT-TS PLOT-GRP

Plot #1:
White—OBS_GRP
    Observed historical flow at GRPC2 basin outlet.
Magenta—GRPC2SIM
    Simulated flow at GRPC2 basin outlet.

Plot #2:
White—OBS_GRP
    Observed historical flow at GRPC2 basin outlet.
Magenta—GRPC2SIM
    Simulated flow at GRPC2 basin outlet.
Yellow—GWR_RGRP
    Groundwater returns below the POUC2 basin outlet and above GRPC2 basin outlet from PLNS reservoir water application.
Red—RIPDV3RL
    Lagged return flows from application of diversion to riparian areas.

Plot #3:
White—OBS_GRP
    Observed historical flow at GRPC2 basin outlet.
Magenta—GRPIN3
    Non-negative difference, GRPIN2L minus RIPDV3
Yellow—RIPDV3RL
    Lagged return flows from application of diversion to riparian areas.
Red—GRPC2SIM
    Simulated flow at GRPC2 basin outlet.

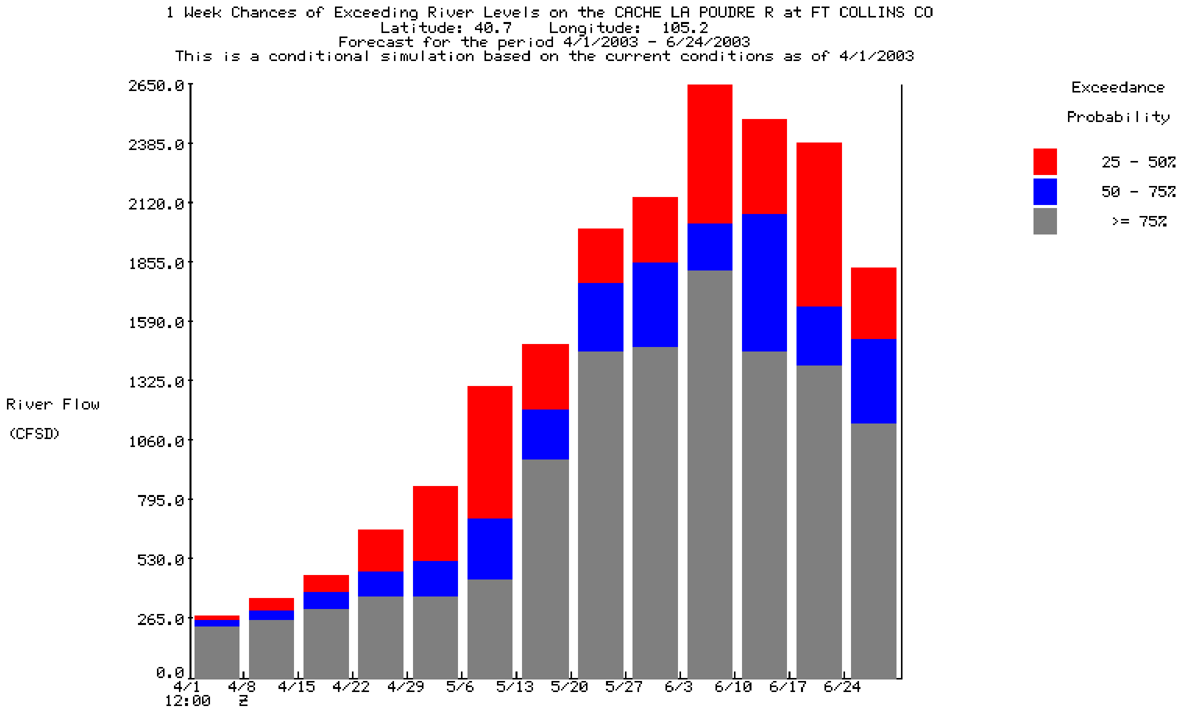
Plot #4
White—GRPIN2L
    Routed version of GRPIN2. (See LAG/K GRPFN08.)
Magenta—RIPDV3
    Diversion from the GRPC2 reach for application to riparian areas.
Yellow—GRPIN3
    Non-negative difference, GRPIN2L minus RIPDV3

Plot #5:
White—GRPIN1
    Outflow from POUC2 basin.
Magenta—GRPWWTP
    Return flows from waste water treatment plants to the GRPC2 reach.
Yellow—GWR_RGRP
    Groundwater returns below the POUC2 basin outlet and above GRPC2 basin outlet from PLNS reservoir water application.
Red—GRP
    Simulated local runoff from GRPC2.
Green—GRPIN2
    Sum of GRPIN1, GRPWWTP, 75% of GWR_RGRP and GRP. (See WEIGH-TS GRPFN06)
Orange—GRPIN2L
    Routed version of GRPIN2. (See LAG/K GRPFN08.)

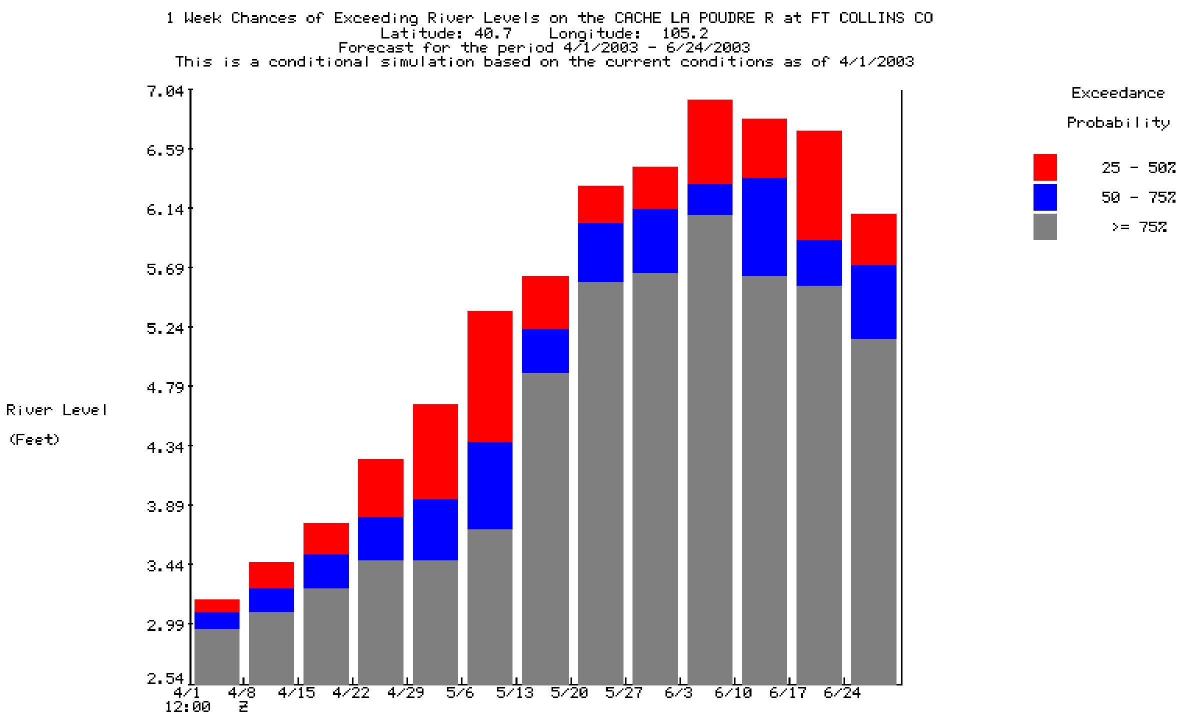
APPENDIX B

Probabilistic Forecast Products

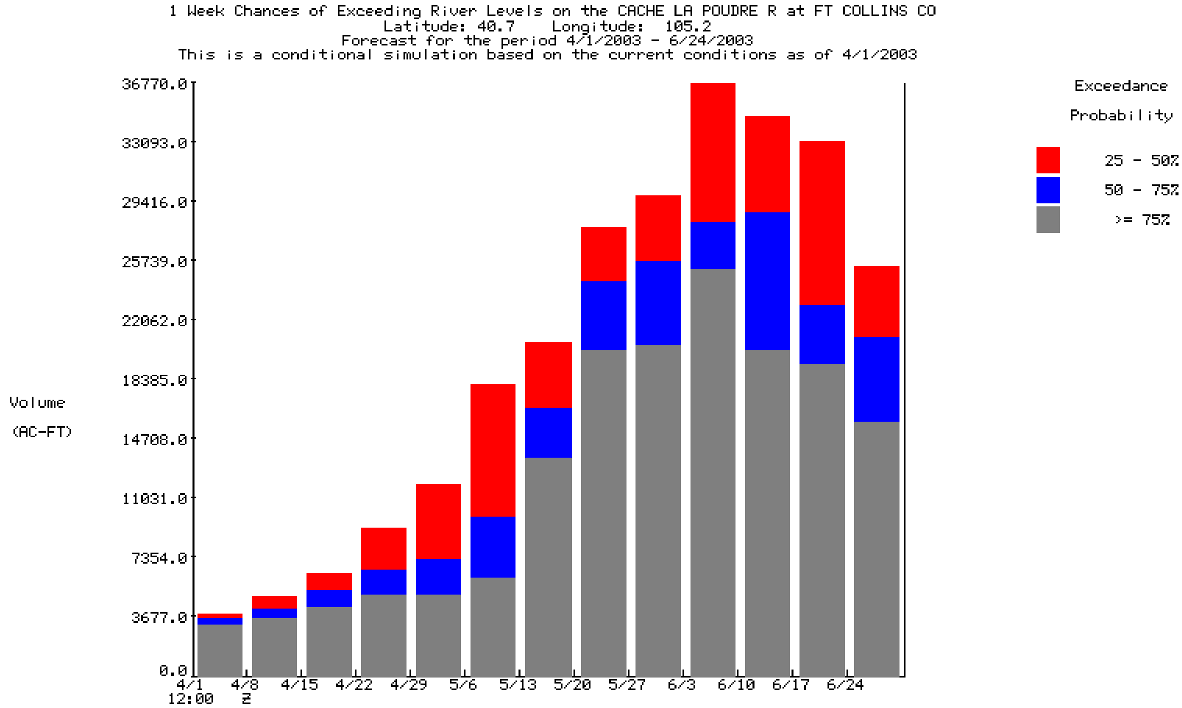
Approach 1: April 1, 2003 weekly histogram of mean discharge



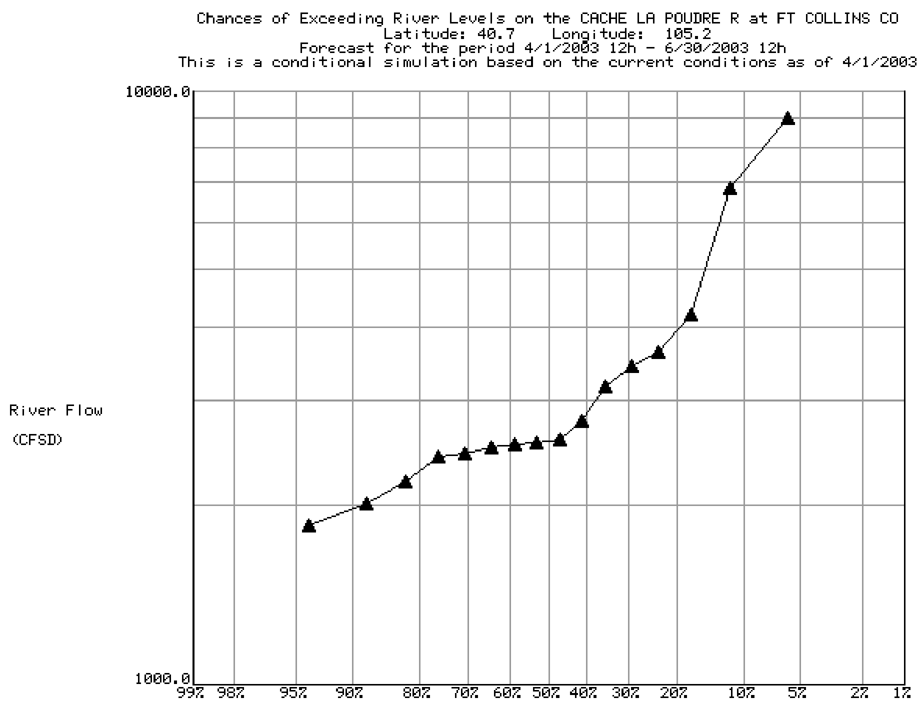
Approach 1: April 1, 2003 weekly histogram of mean stage



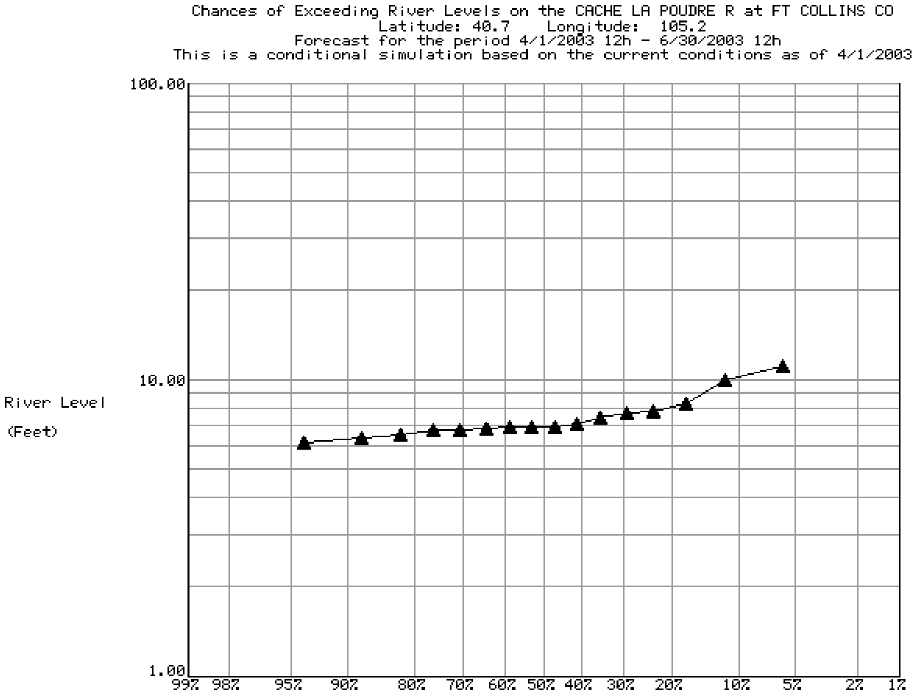
Approach 1: April 1, 2003 weekly histogram of total volume



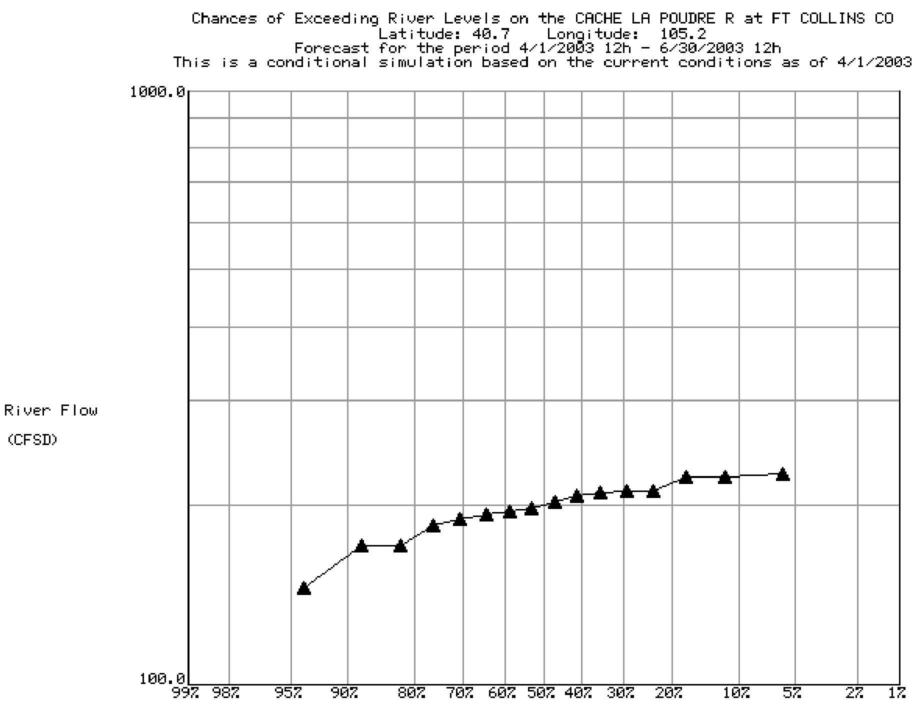
Approach 1: April 1, 2003 90-day exceedance plot of peak discharge



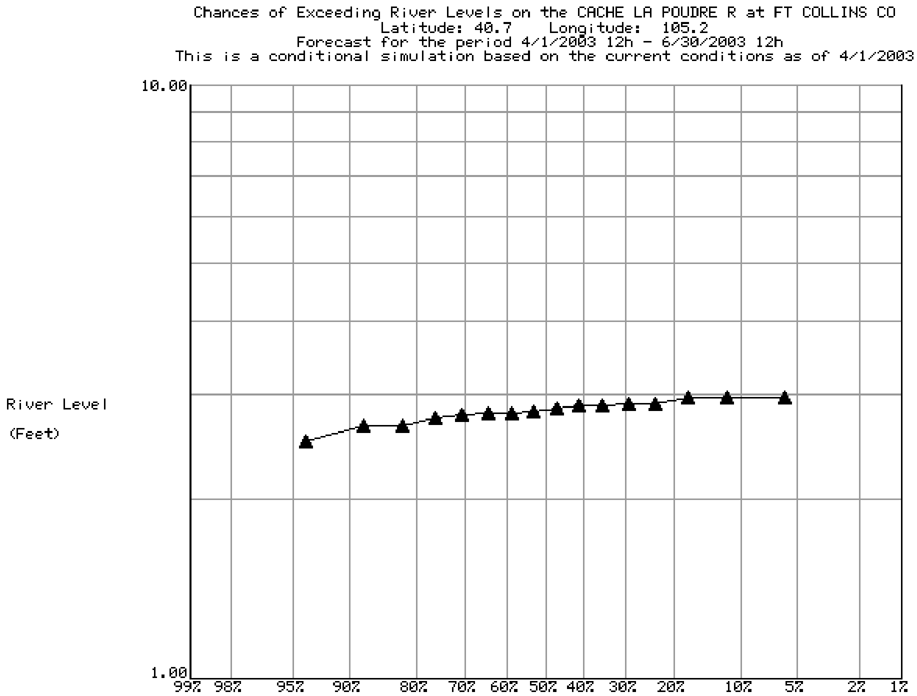
Approach 1: April 1, 2003 90-day exceedance plot of peak stage



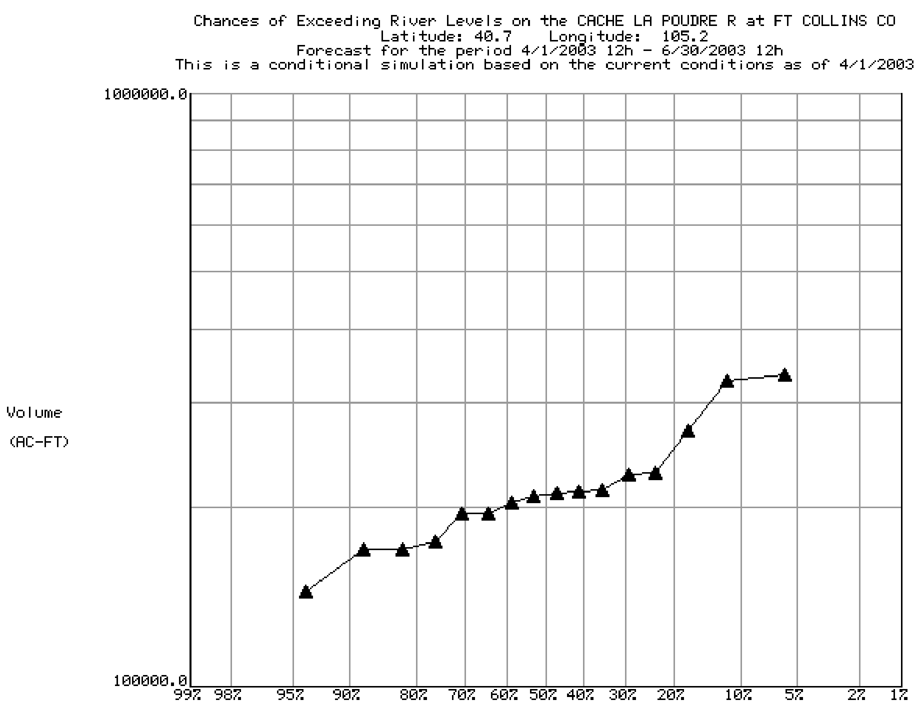
Approach 1: April 1, 2003 90-day exceedance plot of minimum discharge



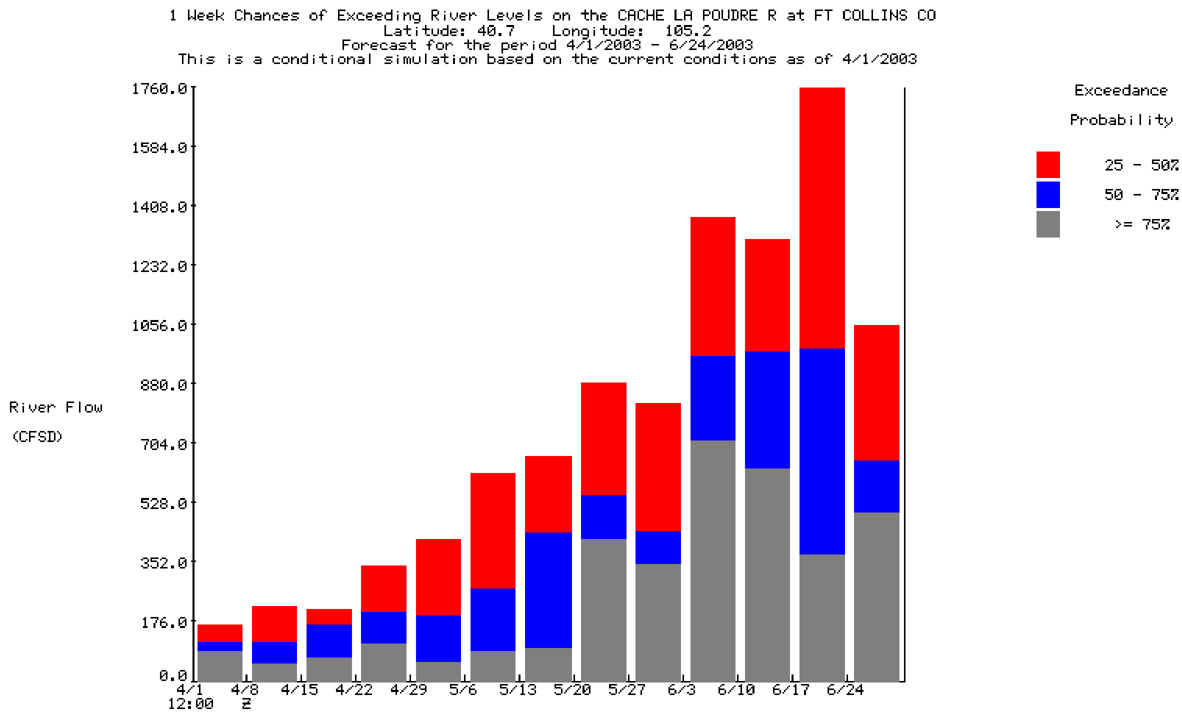
Approach 1: April 1, 2003 90-day exceedance plot of minimum stage



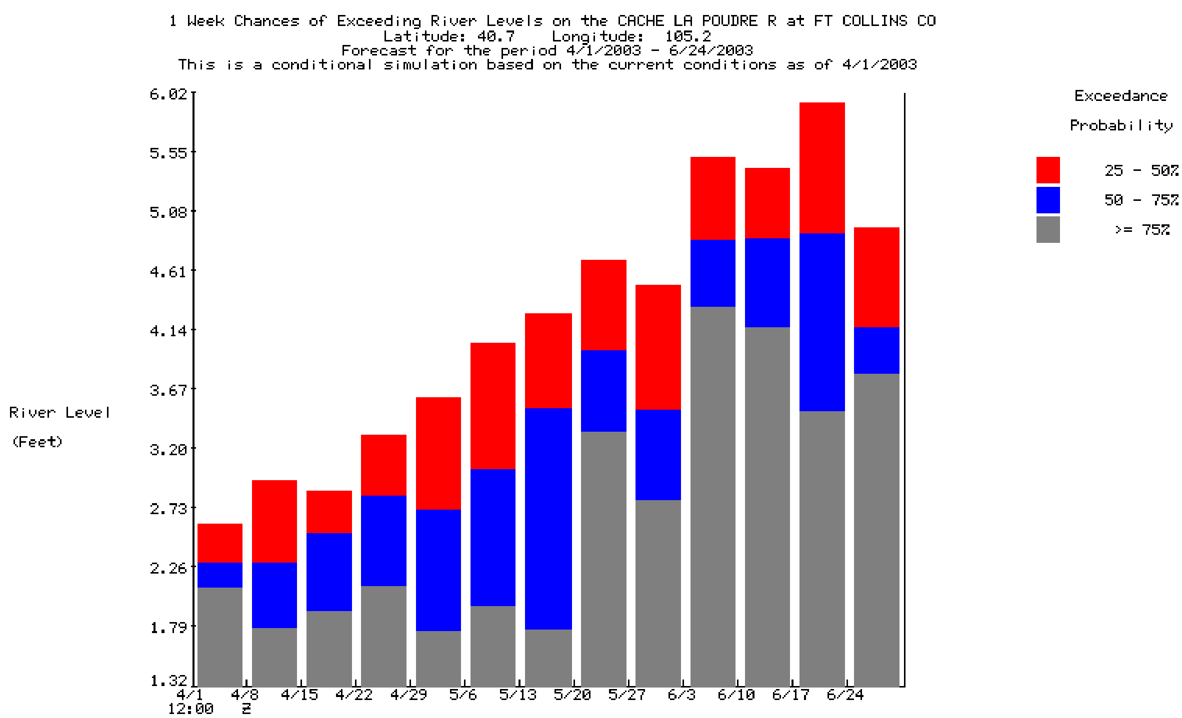
Approach 1: April 1, 2003 90-day exceedance plot of total volume



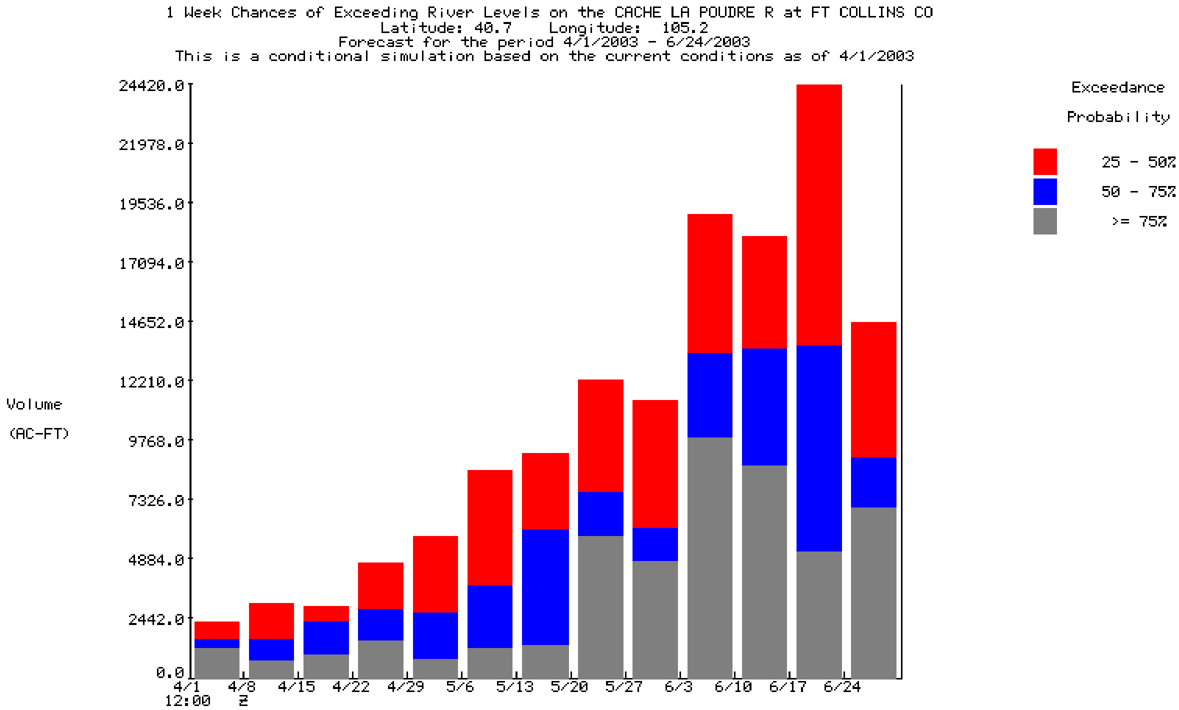
Approach 2: April 1, 2003 weekly histogram of mean discharge



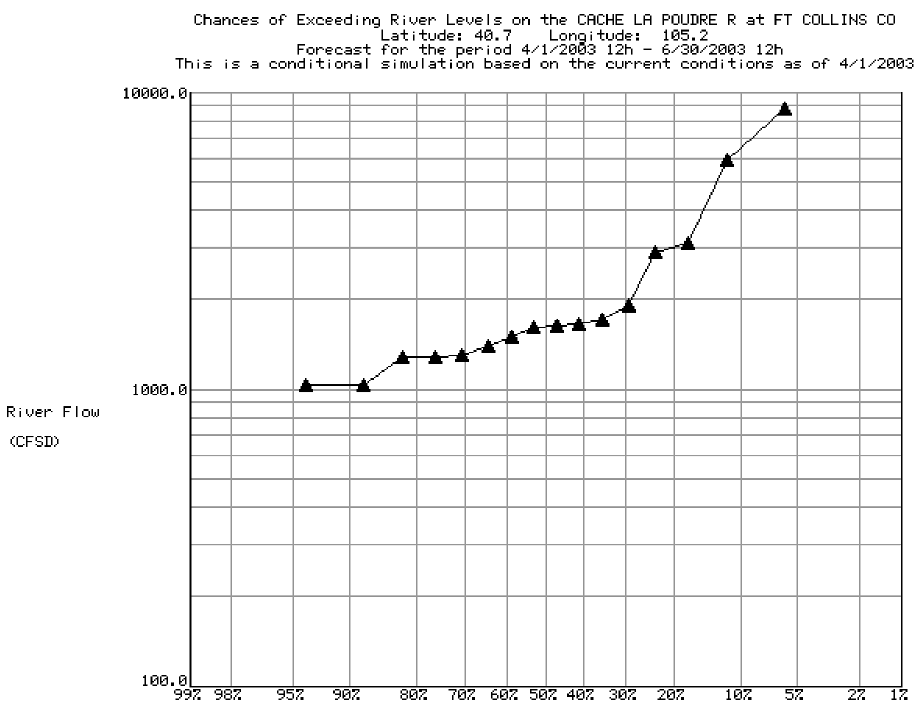
Approach 2: April 1, 2003 weekly histogram of mean stage



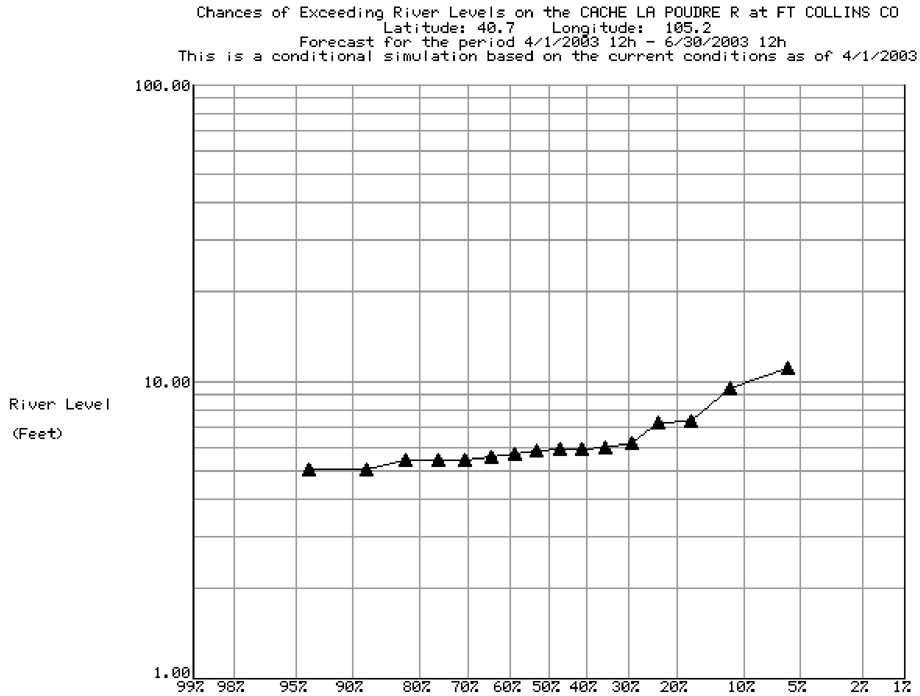
Approach 2: April 1, 2003 weekly histogram of total volume



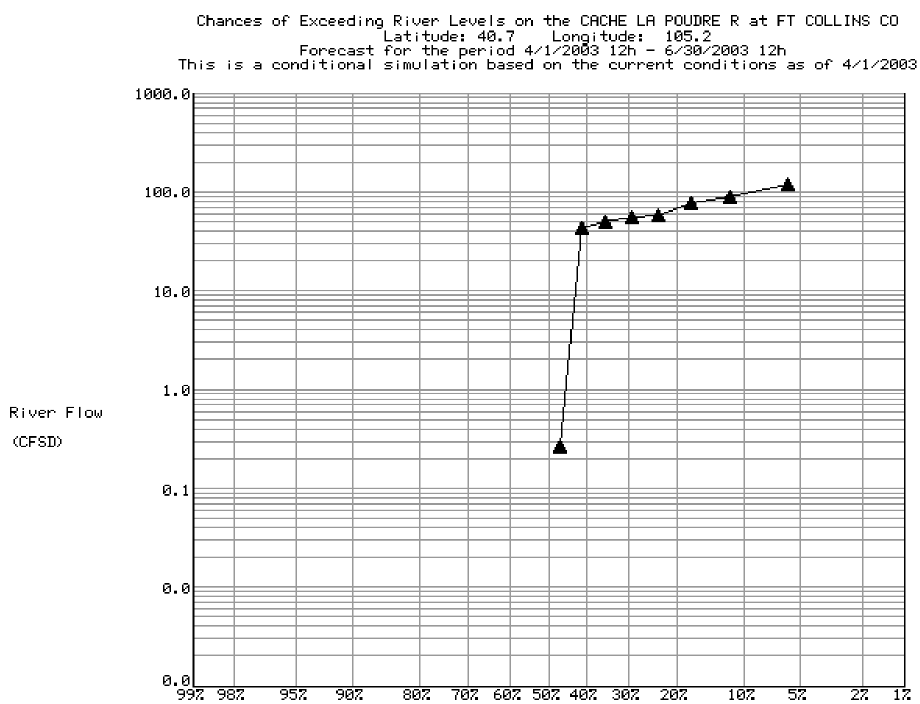
Approach 2: April 1, 2003 90-day exceedance plot of peak discharge



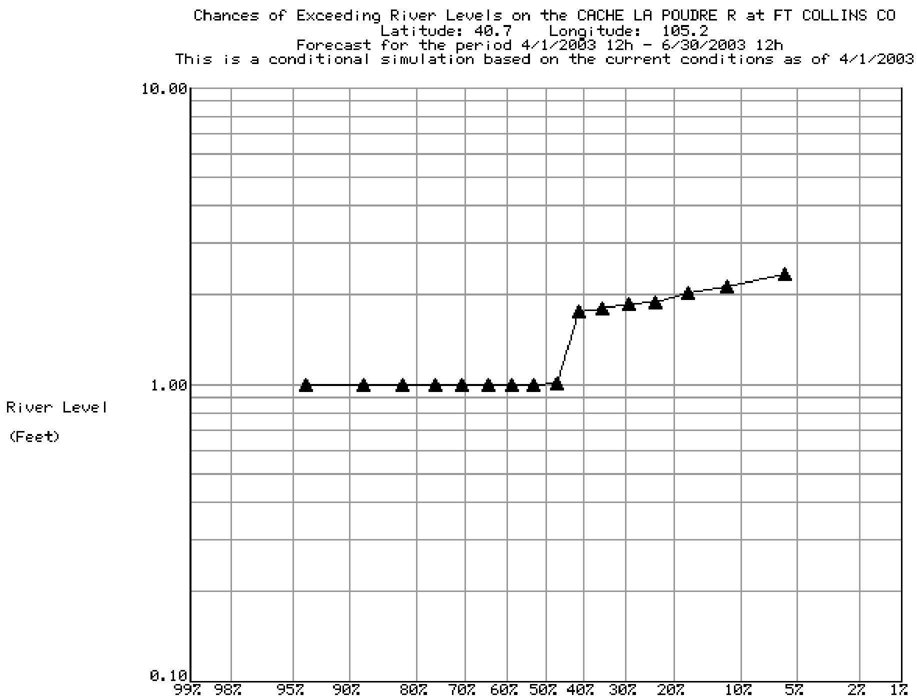
Approach 2: April 1, 2003 90-day exceedance plot of peak stage



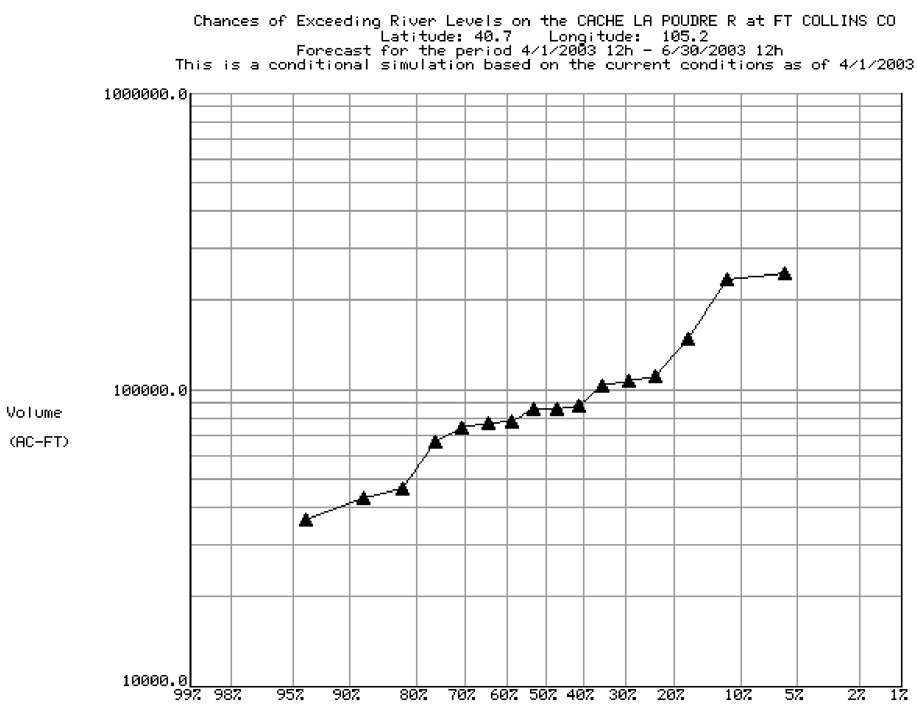
Approach 2: April 1, 2003 90-day exceedance plot of minimum discharge



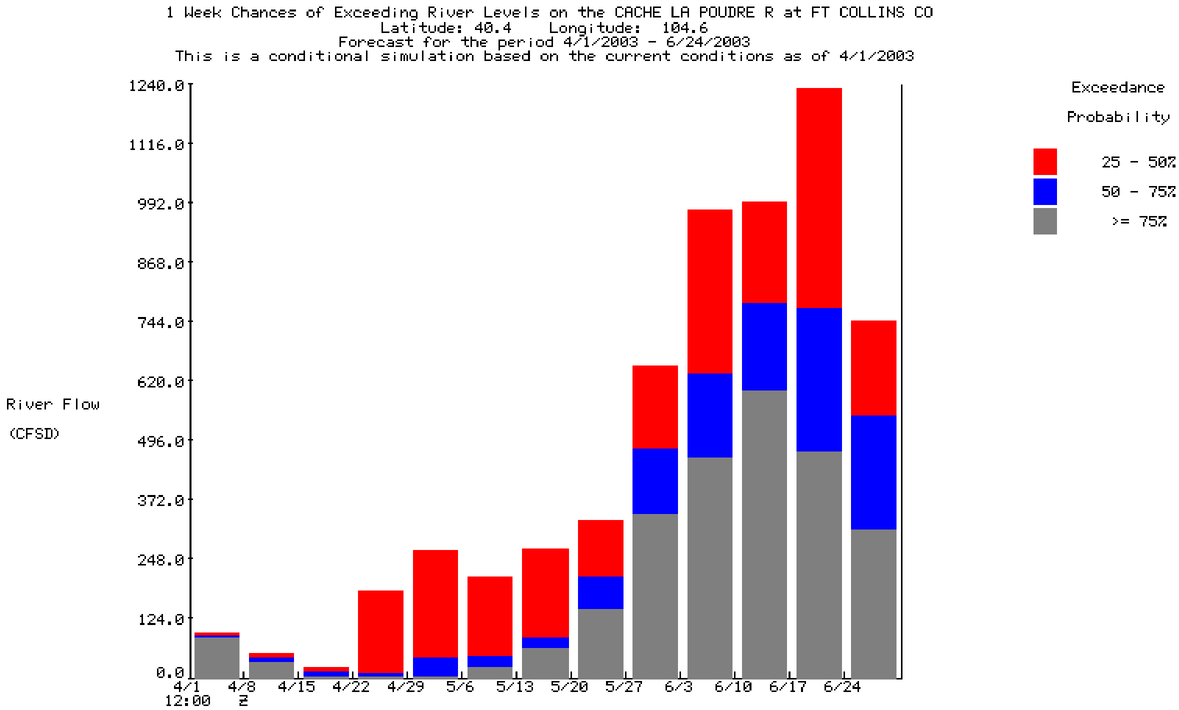
Approach 2: April 1, 2003 90-day exceedance plot of minimum stage



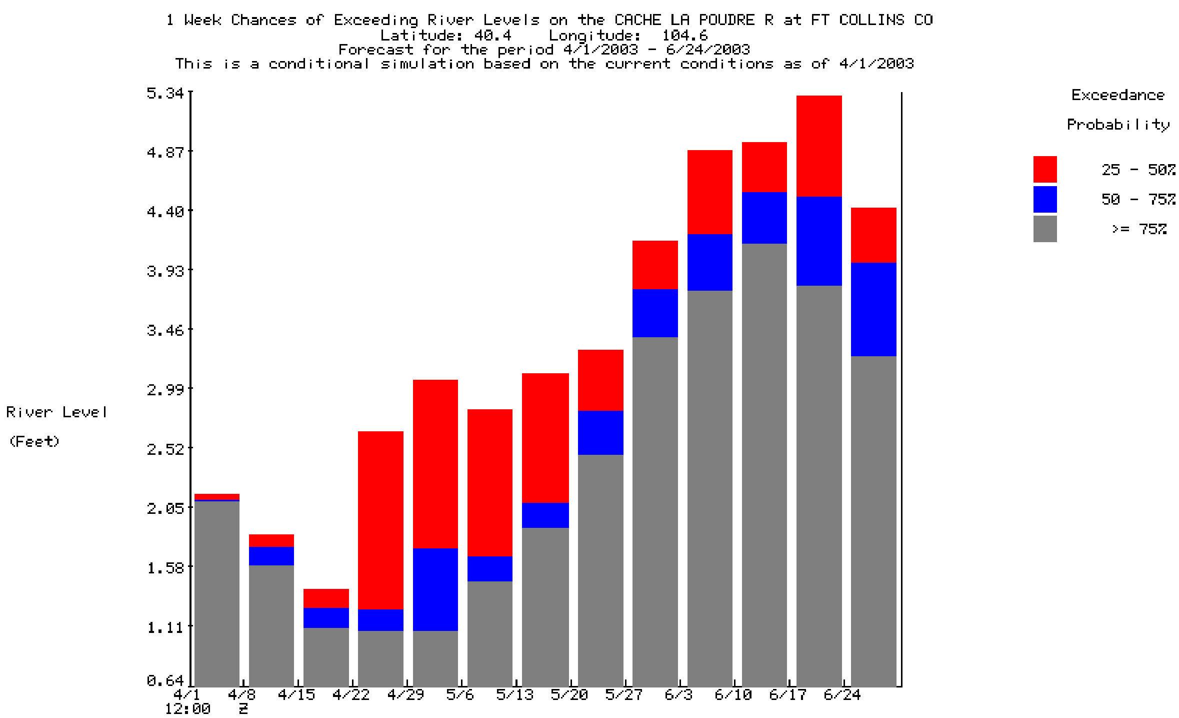
Approach 2: April 1, 2003 90-day exceedance plot of total volume



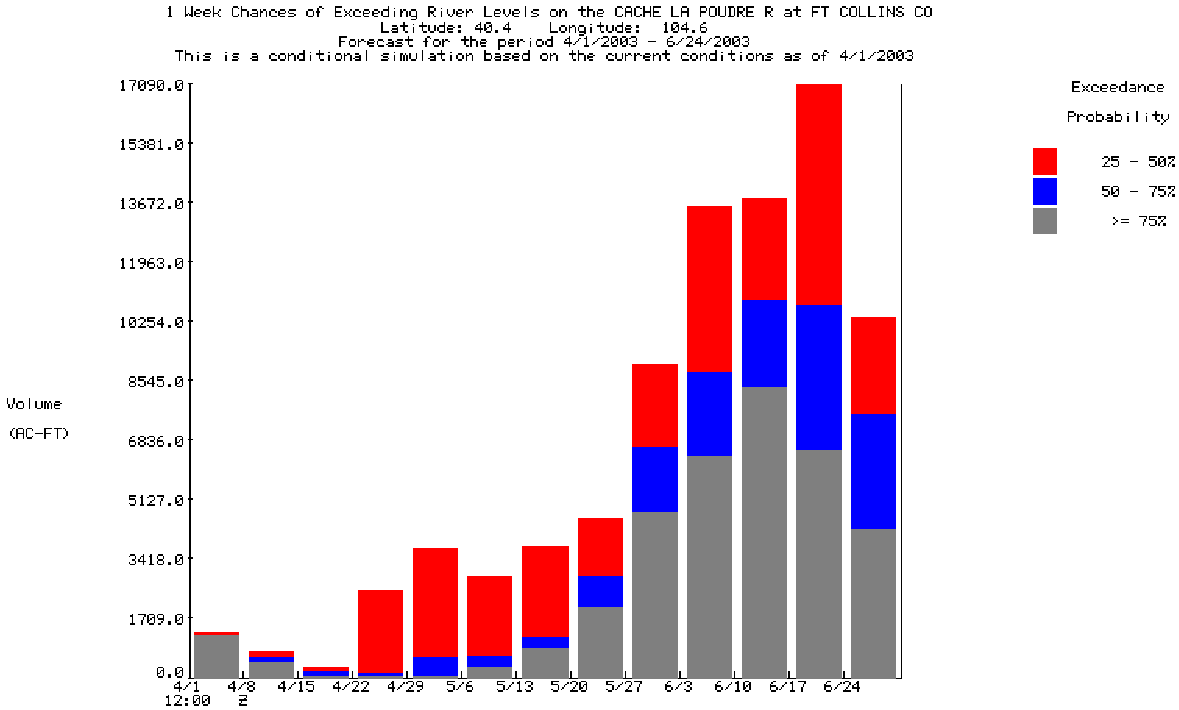
Approach 3: April 1, 2003 weekly histogram of mean discharge



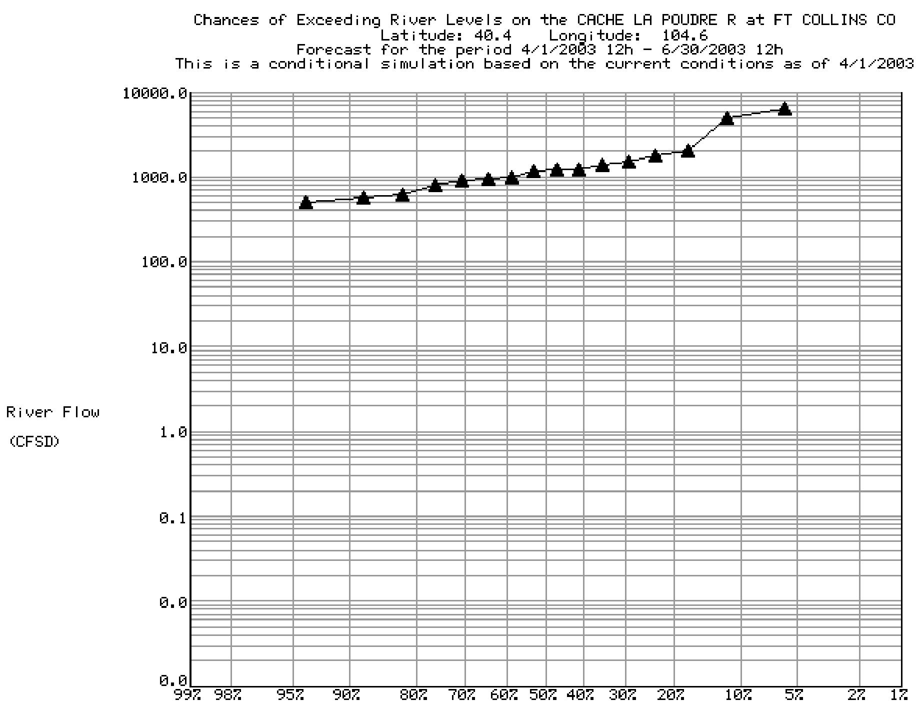
Approach 3: April 1, 2003 weekly histogram of mean stage



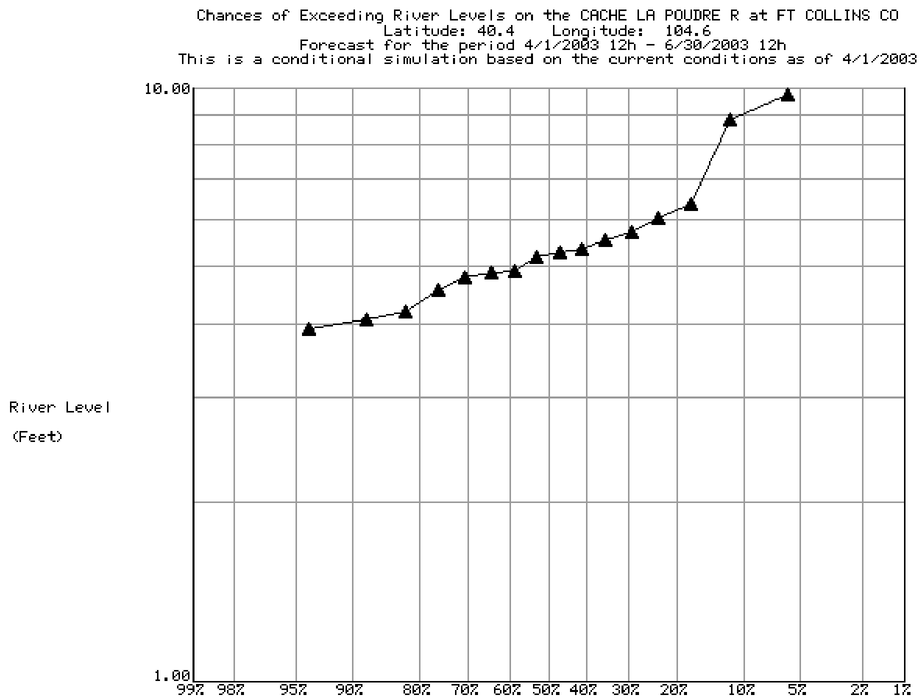
Approach 3: April 1, 2003 weekly histogram of total volume



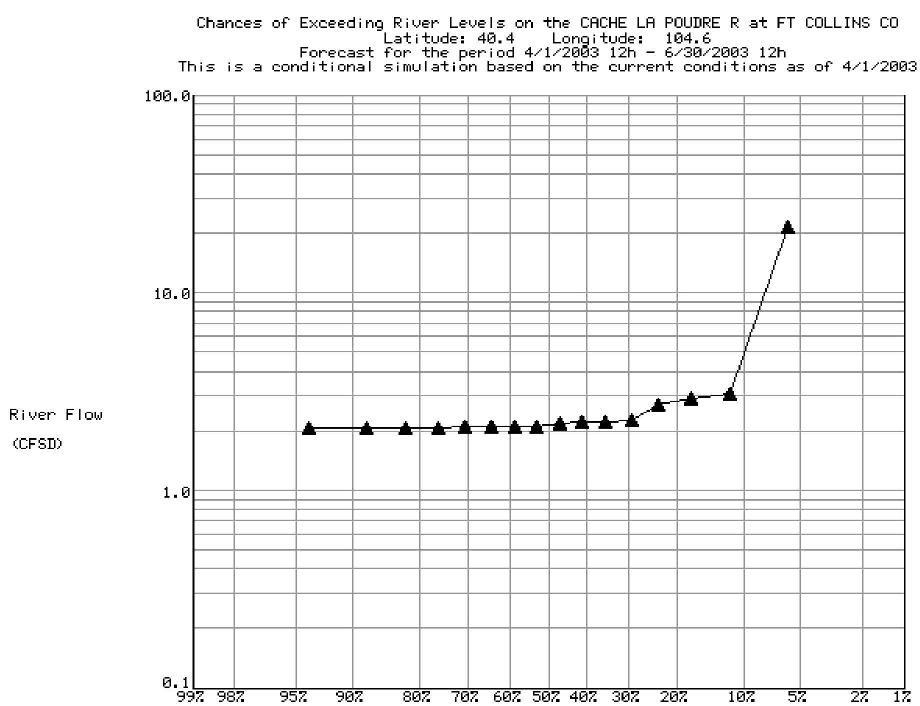
Approach 3: April 1, 2003 90-day exceedance plot of peak discharge



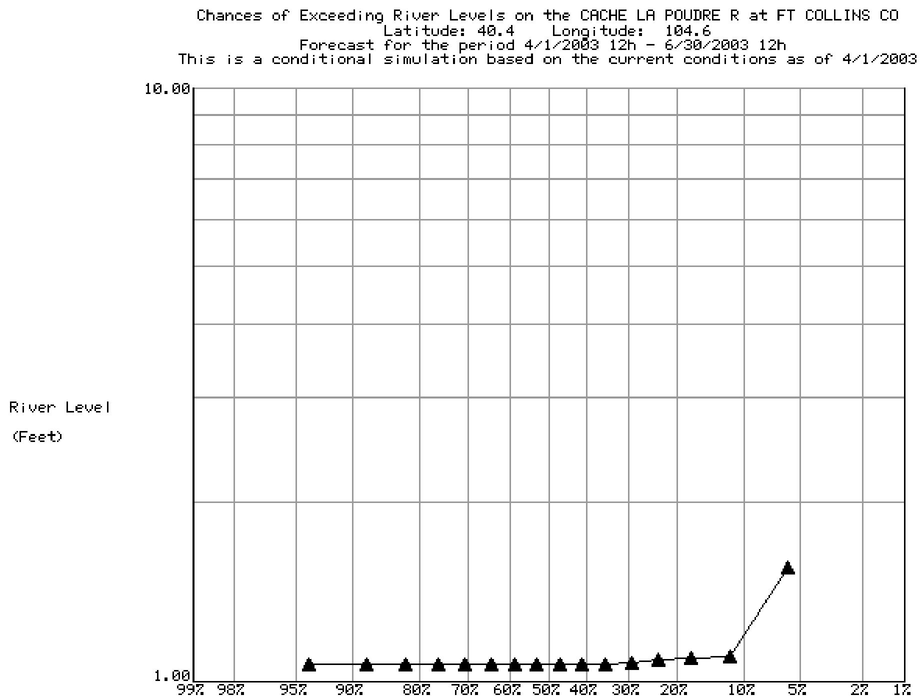
Approach 3: April 1, 2003 90-day exceedance plot of peak stage



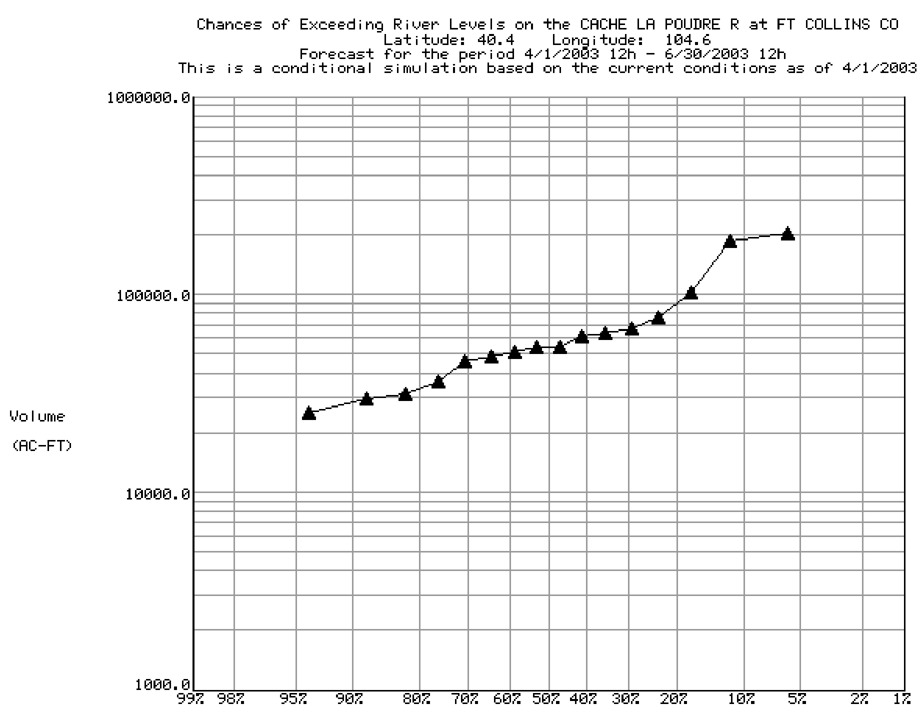
Approach 3: April 1, 2003 90-day exceedance plot of minimum discharge



Approach 3: April 1, 2003 90-day exceedance plot of minimum stage



Approach 3: April 1, 2003 90-day exceedance plot of total volume



APPENDIX C

Sample RPSS Statistics Output

Portion of the RPSS Output Table (*.iwk) for the POUC2 July 1, 90-day, Total Volume Forecast

```
    Statistics for 1988 ( observed was 3864.639 )

Climate                                                             2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.143   1.000   0.143   1.000 |   0.734
   5400.000    7797.000 |   0.143   0.000   0.286   1.000 |   0.510
   7797.000    9952.000 |   0.143   0.000   0.429   1.000 |   0.326
   9952.000   12015.000 |   0.144   0.000   0.572   1.000 |   0.183
  12015.000   21196.000 |   0.143   0.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    1.855

Forecast                                                            2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.000   1.000   0.000   1.000 |   1.000
   5400.000    7797.000 |   0.000   0.000   0.000   1.000 |   1.000
   7797.000    9952.000 |   0.000   0.000   0.000   1.000 |   1.000
   9952.000   12015.000 |   0.875   0.000   0.875   1.000 |   0.016
  12015.000   21196.000 |   0.062   0.000   0.938   1.000 |   0.004
  21196.000   31142.000 |   0.000   0.000   0.938   1.000 |   0.004
   31142.00             |   0.062   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    3.023

                                                   RPSS =  -63.001


    Statistics for 1989.000 ( observed was 10925.148 )

Climate                                                             2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.143   0.000   0.143   0.000 |   0.020
   5400.000    7797.000 |   0.143   0.000   0.286   0.000 |   0.082
   7797.000    9952.000 |   0.143   0.000   0.429   0.000 |   0.184
   9952.000   12015.000 |   0.144   1.000   0.572   1.000 |   0.183
  12015.000   21196.000 |   0.143   0.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    0.571

Forecast                                                            2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.000   0.000   0.000   0.000 |   0.000
   5400.000    7797.000 |   0.000   0.000   0.000   0.000 |   0.000
   7797.000    9952.000 |   0.062   0.000   0.062   0.000 |   0.004
   9952.000   12015.000 |   0.125   1.000   0.188   1.000 |   0.660
  12015.000   21196.000 |   0.750   0.000   0.938   1.000 |   0.004
  21196.000   31142.000 |   0.000   0.000   0.938   1.000 |   0.004
   31142.00             |   0.062   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    0.672

                                                   RPSS =  -17.763
```

```
    Statistics for 1990.000 ( observed was 9158.754 )

Climate                                                          2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.143   0.000   0.143   0.000 |   0.020
   5400.000    7797.000 |   0.143   0.000   0.286   0.000 |   0.082
   7797.000    9952.000 |   0.143   1.000   0.429   1.000 |   0.326
   9952.000   12015.000 |   0.144   0.000   0.572   1.000 |   0.183
  12015.000   21196.000 |   0.143   0.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    0.713

Forecast                                                         2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.000   0.000   0.000   0.000 |   0.000
   5400.000    7797.000 |   0.000   0.000   0.000   0.000 |   0.000
   7797.000    9952.000 |   0.375   1.000   0.375   1.000 |   0.391
   9952.000   12015.000 |   0.562   0.000   0.938   1.000 |   0.004
  12015.000   21196.000 |   0.000   0.000   0.938   1.000 |   0.004
  21196.000   31142.000 |   0.000   0.000   0.938   1.000 |   0.004
   31142.00             |   0.062   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    0.402

                                                   RPSS =   43.576


    Statistics for 1991.000 ( observed was 9659.669 )

Climate                                                          2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.143   0.000   0.143   0.000 |   0.020
   5400.000    7797.000 |   0.143   0.000   0.286   0.000 |   0.082
   7797.000    9952.000 |   0.143   1.000   0.429   1.000 |   0.326
   9952.000   12015.000 |   0.144   0.000   0.572   1.000 |   0.183
  12015.000   21196.000 |   0.143   0.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    0.713

Forecast                                                         2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
------------------------+---------------------------------+--------
      0.000    5400.000 |   0.000   0.000   0.000   0.000 |   0.000
   5400.000    7797.000 |   0.000   0.000   0.000   0.000 |   0.000
   7797.000    9952.000 |   0.000   1.000   0.000   1.000 |   1.000
   9952.000   12015.000 |   0.438   0.000   0.438   1.000 |   0.316
  12015.000   21196.000 |   0.500   0.000   0.938   1.000 |   0.004
  21196.000   31142.000 |   0.000   0.000   0.938   1.000 |   0.004
   31142.00             |   0.062   0.000   1.000   1.000 |   0.000
------------------------+---------------------------------+--------
                                                    RPS =    1.324

                                                   RPSS =  -85.708
```

Statistics for 1992.000 (observed was 7208.835)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	1.000	0.286	1.000	0.510
7797.000	9952.000	0.143	0.000	0.429	1.000	0.326
9952.000	12015.000	0.144	0.000	0.572	1.000	0.183
12015.000	21196.000	0.143	0.000	0.715	1.000	0.081
21196.000	31142.000	0.143	0.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 1.141

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	1.000	0.000	1.000	1.000
7797.000	9952.000	0.000	0.000	0.000	1.000	1.000
9952.000	12015.000	0.000	0.000	0.000	1.000	1.000
12015.000	21196.000	0.938	0.000	0.938	1.000	0.004
21196.000	31142.000	0.000	0.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 3.008

RPSS = -163.648

Statistics for 1993.000 (observed was 22542.010)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	0.000	0.286	0.000	0.082
7797.000	9952.000	0.143	0.000	0.429	0.000	0.184
9952.000	12015.000	0.144	0.000	0.572	0.000	0.327
12015.000	21196.000	0.143	0.000	0.715	0.000	0.511
21196.000	31142.000	0.143	1.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 1.145

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	0.000	0.000	0.000	0.000
7797.000	9952.000	0.000	0.000	0.000	0.000	0.000
9952.000	12015.000	0.312	0.000	0.312	0.000	0.098
12015.000	21196.000	0.625	0.000	0.938	0.000	0.879
21196.000	31142.000	0.000	1.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 0.980

RPSS = 14.355

Statistics for 1994.000 (observed was 7816.483)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	0.000	0.286	0.000	0.082
7797.000	9952.000	0.143	1.000	0.429	1.000	0.326
9952.000	12015.000	0.144	0.000	0.572	1.000	0.183
12015.000	21196.000	0.143	0.000	0.715	1.000	0.081
21196.000	31142.000	0.143	0.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 0.713

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	0.000	0.000	0.000	0.000
7797.000	9952.000	0.062	1.000	0.062	1.000	0.879
9952.000	12015.000	0.188	0.000	0.250	1.000	0.562
12015.000	21196.000	0.688	0.000	0.938	1.000	0.004
21196.000	31142.000	0.000	0.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 1.449

RPSS = -103.238

Statistics for 1995.000 (observed was 35171.988)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	0.000	0.286	0.000	0.082
7797.000	9952.000	0.143	0.000	0.429	0.000	0.184
9952.000	12015.000	0.144	0.000	0.572	0.000	0.327
12015.000	21196.000	0.143	0.000	0.715	0.000	0.511
21196.000	31142.000	0.143	0.000	0.858	0.000	0.736
31142.00		0.142	1.000	1.000	1.000	0.000

RPS = 1.861

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	0.000	0.000	0.000	0.000
7797.000	9952.000	0.000	0.000	0.000	0.000	0.000
9952.000	12015.000	0.000	0.000	0.000	0.000	0.000
12015.000	21196.000	0.062	0.000	0.062	0.000	0.004
21196.000	31142.000	0.875	0.000	0.938	0.000	0.879
31142.00		0.062	1.000	1.000	1.000	0.000

RPS = 0.883

RPSS = 52.558

```
    Statistics for 1996.000 ( observed was 20756.436 )

Climate                                                         2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.143   0.000   0.143   0.000 |   0.020
   5400.000    7797.000 |   0.143   0.000   0.286   0.000 |   0.082
   7797.000    9952.000 |   0.143   0.000   0.429   0.000 |   0.184
   9952.000   12015.000 |   0.144   0.000   0.572   0.000 |   0.327
  12015.000   21196.000 |   0.143   1.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    0.715

Forecast                                                        2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.000   0.000   0.000   0.000 |   0.000
   5400.000    7797.000 |   0.000   0.000   0.000   0.000 |   0.000
   7797.000    9952.000 |   0.000   0.000   0.000   0.000 |   0.000
   9952.000   12015.000 |   0.688   0.000   0.688   0.000 |   0.473
  12015.000   21196.000 |   0.250   1.000   0.938   1.000 |   0.004
  21196.000   31142.000 |   0.000   0.000   0.938   1.000 |   0.004
   31142.00             |   0.062   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    0.480

                                                   RPSS =   32.808


    Statistics for 1997.000 ( observed was 42448.949 )

Climate                                                         2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.143   0.000   0.143   0.000 |   0.020
   5400.000    7797.000 |   0.143   0.000   0.286   0.000 |   0.082
   7797.000    9952.000 |   0.143   0.000   0.429   0.000 |   0.184
   9952.000   12015.000 |   0.144   0.000   0.572   0.000 |   0.327
  12015.000   21196.000 |   0.143   0.000   0.715   0.000 |   0.511
  21196.000   31142.000 |   0.143   0.000   0.858   0.000 |   0.736
   31142.00             |   0.142   1.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    1.861

Forecast                                                        2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.000   0.000   0.000   0.000 |   0.000
   5400.000    7797.000 |   0.000   0.000   0.000   0.000 |   0.000
   7797.000    9952.000 |   0.312   0.000   0.312   0.000 |   0.098
   9952.000   12015.000 |   0.500   0.000   0.812   0.000 |   0.660
  12015.000   21196.000 |   0.125   0.000   0.938   0.000 |   0.879
  21196.000   31142.000 |   0.000   0.000   0.938   0.000 |   0.879
   31142.00             |   0.062   1.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    2.516

                                                   RPSS =  -35.188
```

Statistics for 1998.000 (observed was 20953.350)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	0.000	0.286	0.000	0.082
7797.000	9952.000	0.143	0.000	0.429	0.000	0.184
9952.000	12015.000	0.144	0.000	0.572	0.000	0.327
12015.000	21196.000	0.143	1.000	0.715	1.000	0.081
21196.000	31142.000	0.143	0.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 0.715

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	0.000	0.000	0.000	0.000
7797.000	9952.000	0.625	0.000	0.625	0.000	0.391
9952.000	12015.000	0.312	0.000	0.938	0.000	0.879
12015.000	21196.000	0.000	1.000	0.938	1.000	0.004
21196.000	31142.000	0.000	0.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 1.277

RPSS = -78.631

Statistics for 1999.000 (observed was 25432.035)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	0.000	0.286	0.000	0.082
7797.000	9952.000	0.143	0.000	0.429	0.000	0.184
9952.000	12015.000	0.144	0.000	0.572	0.000	0.327
12015.000	21196.000	0.143	0.000	0.715	0.000	0.511
21196.000	31142.000	0.143	1.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 1.145

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	0.000	0.000	0.000	0.000
7797.000	9952.000	0.000	0.000	0.000	0.000	0.000
9952.000	12015.000	0.000	0.000	0.000	0.000	0.000
12015.000	21196.000	0.938	0.000	0.938	0.000	0.879
21196.000	31142.000	0.000	1.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 0.883

RPSS = 22.885

Statistics for 2000.000 (observed was 12420.989)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	0.000	0.286	0.000	0.082
7797.000	9952.000	0.143	0.000	0.429	0.000	0.184
9952.000	12015.000	0.144	0.000	0.572	0.000	0.327
12015.000	21196.000	0.143	1.000	0.715	1.000	0.081
21196.000	31142.000	0.143	0.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 0.715

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	0.000	0.000	0.000	0.000
7797.000	9952.000	0.000	0.000	0.000	0.000	0.000
9952.000	12015.000	0.062	0.000	0.062	0.000	0.004
12015.000	21196.000	0.875	1.000	0.938	1.000	0.004
21196.000	31142.000	0.000	0.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 0.012

RPSS = 98.361

Statistics for 2001.000 (observed was 7673.327)

Climate

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.143	0.000	0.143	0.000	0.020
5400.000	7797.000	0.143	1.000	0.286	1.000	0.510
7797.000	9952.000	0.143	0.000	0.429	1.000	0.326
9952.000	12015.000	0.144	0.000	0.572	1.000	0.183
12015.000	21196.000	0.143	0.000	0.715	1.000	0.081
21196.000	31142.000	0.143	0.000	0.858	1.000	0.020
31142.00		0.142	0.000	1.000	1.000	0.000

RPS = 1.141

Forecast

>=	<	Prob	Obs	CumProb	CumObs	$(CP-CO)^2$
0.000	5400.000	0.000	0.000	0.000	0.000	0.000
5400.000	7797.000	0.000	1.000	0.000	1.000	1.000
7797.000	9952.000	0.062	0.000	0.062	1.000	0.879
9952.000	12015.000	0.812	0.000	0.875	1.000	0.016
12015.000	21196.000	0.062	0.000	0.938	1.000	0.004
21196.000	31142.000	0.000	0.000	0.938	1.000	0.004
31142.00		0.062	0.000	1.000	1.000	0.000

RPS = 1.902

RPSS = -66.749

```
    Statistics for 2002.000 ( observed was 4030.650 )

Climate                                                          2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.143   1.000   0.143   1.000 |   0.734
   5400.000    7797.000 |   0.143   0.000   0.286   1.000 |   0.510
   7797.000    9952.000 |   0.143   0.000   0.429   1.000 |   0.326
   9952.000   12015.000 |   0.144   0.000   0.572   1.000 |   0.183
  12015.000   21196.000 |   0.143   0.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    1.855

Forecast                                                         2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.062   1.000   0.062   1.000 |   0.879
   5400.000    7797.000 |   0.875   0.000   0.938   1.000 |   0.004
   7797.000    9952.000 |   0.000   0.000   0.938   1.000 |   0.004
   9952.000   12015.000 |   0.000   0.000   0.938   1.000 |   0.004
  12015.000   21196.000 |   0.062   0.000   1.000   1.000 |   0.000
  21196.000   31142.000 |   0.000   0.000   1.000   1.000 |   0.000
   31142.00             |   0.000   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    0.891

                                                   RPSS =   51.984


    Statistics for 2003.000 ( observed was 10673.067 )

Climate                                                          2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.143   0.000   0.143   0.000 |   0.020
   5400.000    7797.000 |   0.143   0.000   0.286   0.000 |   0.082
   7797.000    9952.000 |   0.143   0.000   0.429   0.000 |   0.184
   9952.000   12015.000 |   0.144   1.000   0.572   1.000 |   0.183
  12015.000   21196.000 |   0.143   0.000   0.715   1.000 |   0.081
  21196.000   31142.000 |   0.143   0.000   0.858   1.000 |   0.020
   31142.00             |   0.142   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    0.571

Forecast                                                         2
         >=           < |    Prob     Obs CumProb  CumObs | (CP-CO)
-----------------------+--------------------------------+--------
      0.000    5400.000 |   0.000   0.000   0.000   0.000 |   0.000
   5400.000    7797.000 |   0.000   0.000   0.000   0.000 |   0.000
   7797.000    9952.000 |   0.000   0.000   0.000   0.000 |   0.000
   9952.000   12015.000 |   0.438   1.000   0.438   1.000 |   0.316
  12015.000   21196.000 |   0.500   0.000   0.938   1.000 |   0.004
  21196.000   31142.000 |   0.000   0.000   0.938   1.000 |   0.004
   31142.00             |   0.062   0.000   1.000   1.000 |   0.000
-----------------------+--------------------------------+--------
                                                    RPS =    0.324

                                                   RPSS =   43.173
```

APPENDIX D

Verification Statistics: Reliability Plots

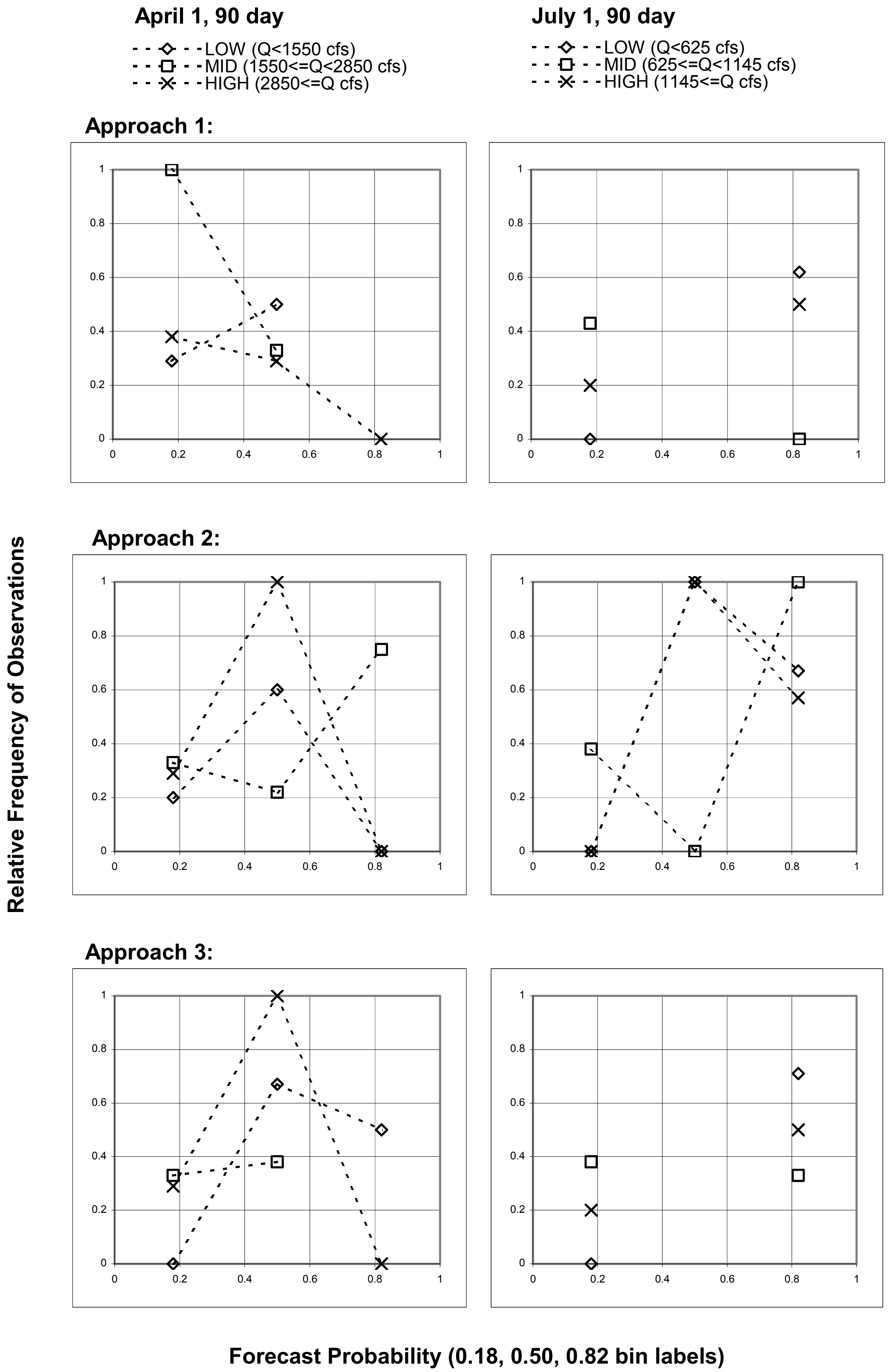


Figure D-1. Reliability Plots for FTDC2, April 1 and July 1, 90-day, Maximum Daily Flow

Reliability table description

The following tables contain the data from the previous plots. For each forecast flow bin, the number of times a given probability range is forecasted for that flow bin is listed in the “F” row. The number of observations in a flow bin when it was forecasted within a given probability range is listed in the “O” row. Finally, the relative frequency of observations is given in the “R” column and is plotted in the Figures.

Table D-1a. Reliability Plot Data for FTDC2, April 1, 90-day, Maximum Daily Flow

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 1

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	1550.000	F	14.000	2.000	0.000
		O	4.00	1.00	0.00
		R	0.29	0.50	-999.99
1550.000	2850.000	F	1.000	15.000	0.000
		O	1.00	5.00	0.00
		R	1.00	0.33	-999.99
2850.000		F	8.000	7.000	1.000
		O	3.00	2.00	0.00
		R	0.38	0.29	0.00

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 2

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	1550.000	F	10.000	5.000	1.000
		O	2.00	3.00	0.00
		R	0.20	0.60	0.00
1550.000	2850.000	F	3.000	9.000	4.000
		O	1.00	2.00	3.00
		R	0.33	0.22	0.75
2850.000		F	14.000	1.000	1.000
		O	4.00	1.00	0.00
		R	0.29	1.00	0.00

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 3

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	1550.000	F	8.000	6.000	2.000
		O	0.00	4.00	1.00
		R	0.00	0.67	0.50
1550.000	2850.000	F	3.000	13.000	0.000
		O	1.00	5.00	0.00
		R	0.33	0.38	-999.99
2850.000		F	14.000	1.000	1.000
		O	4.00	1.00	0.00
		R	0.29	1.00	0.00

Table D-1b. Reliability Plot Data for FTDC2, July 1, 90-day, Maximum Daily Flow

FTDC2 July 1, 90-day Maximum Daily Flow: Approach 1

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	625.000	F	8.000	0.000	8.000
		O	0.00	0.00	5.00
		R	0.00	-999.99	0.62
625.000	1145.000	F	14.000	0.000	2.000
		O	6.00	0.00	0.00
		R	0.43	-999.99	0.00
1145.000		F	10.000	0.000	6.000
		O	2.00	0.00	3.00
		R	0.20	-999.99	0.50

FTDC2 July 1, 90-day Maximum Daily Flow: Approach 2

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	625.000	F	9.000	1.000	6.000
		O	0.00	1.00	4.00
		R	0.00	1.00	0.67
625.000	1145.000	F	13.000	2.000	1.000
		O	5.00	0.00	1.00
		R	0.38	0.00	1.00
1145.000		F	8.000	1.000	7.000
		O	0.00	1.00	4.00
		R	0.00	1.00	0.57

FTDC2 July 1, 90-day Maximum Daily Flow: Approach 3

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	625.000	F	9.000	0.000	7.000
		O	0.00	0.00	5.00
		R	0.00	-999.99	0.71
625.000	1145.000	F	13.000	0.000	3.000
		O	5.00	0.00	1.00
		R	0.38	-999.99	0.33
1145.000		F	10.000	0.000	6.000
		O	2.00	0.00	3.00
		R	0.20	-999.99	0.50

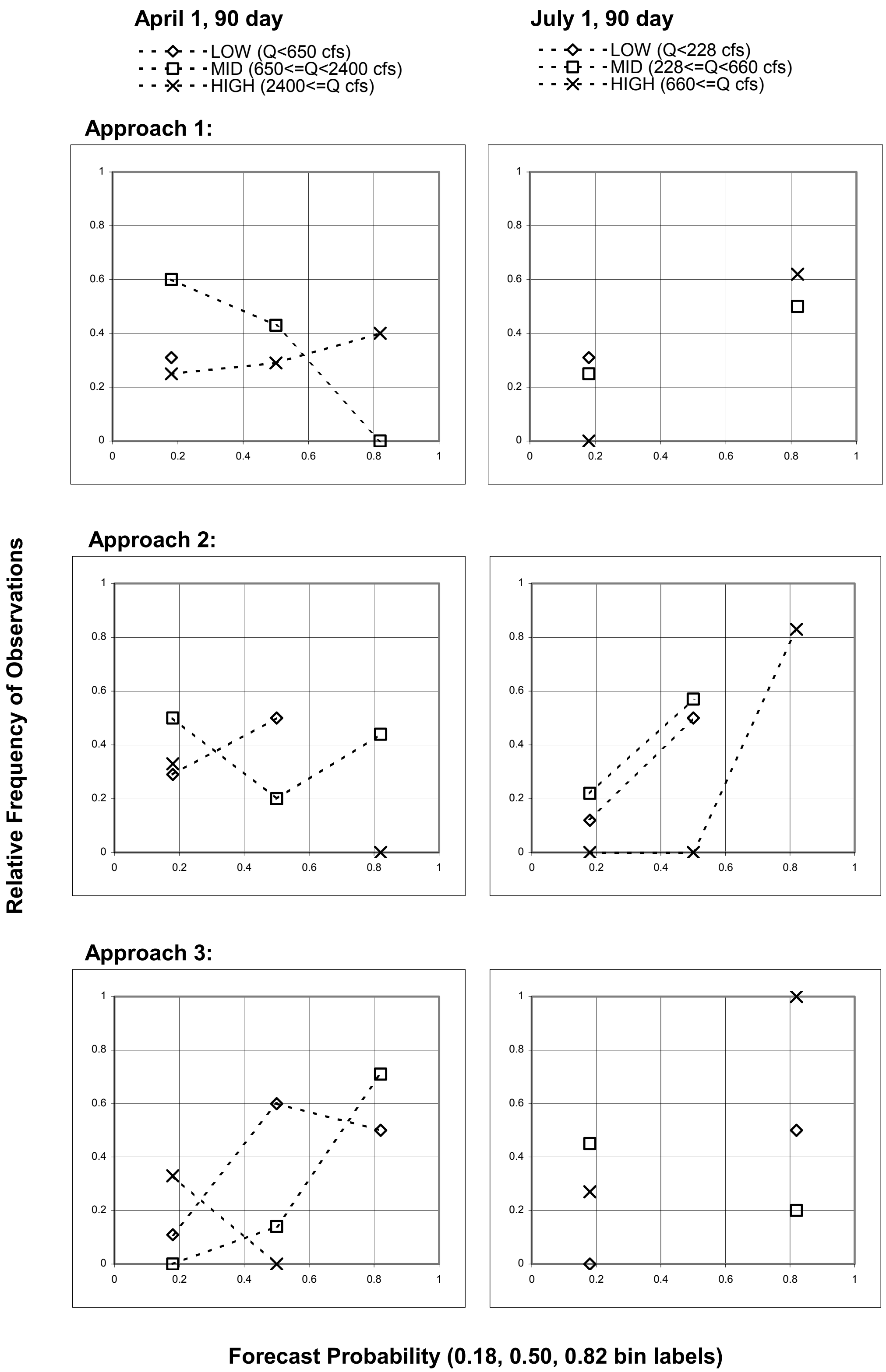


Figure D-2. Reliability Plots for POUC2, April 1 and July 1, 90-day, Maximum Daily Flow

Table D-2a. Reliability Plot Data for POUC2, April 1, 90-day, Maximum Daily Flow

POUC2 April 1, 90-day Maximum Daily Flow: Approach 1

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	650.000	F	16.000	0.000	0.000
		O	5.00	0.00	0.00
		R	0.31	-999.99	-999.99
650.000	2400.000	F	5.000	7.000	4.000
		O	3.00	3.00	0.00
		R	0.60	0.43	0.00
2400.000		F	4.000	7.000	5.000
		O	1.00	2.00	2.00
		R	0.25	0.29	0.40

POUC2 April 1, 90-day Maximum Daily Flow: Approach 2

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	650.000	F	14.000	2.000	0.000
		O	4.00	1.00	0.00
		R	0.29	0.50	-999.99
650.000	2400.000	F	2.000	5.000	9.000
		O	1.00	1.00	4.00
		R	0.50	0.20	0.44
2400.000		F	15.000	0.000	1.000
		O	5.00	0.00	0.00
		R	0.33	-999.99	0.00

POUC2 April 1, 90-day Maximum Daily Flow: Approach 3

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	650.000	F	9.000	5.000	2.000
		O	1.00	3.00	1.00
		R	0.11	0.60	0.50
650.000	2400.000	F	2.000	7.000	7.000
		O	0.00	1.00	5.00
		R	0.00	0.14	0.71
2400.000		F	15.000	1.000	0.000
		O	5.00	0.00	0.00
		R	0.33	0.00	-999.99

Table D-2b. Reliability Plot Data for POUC2, July 1, 90-day, Maximum Daily Flow

```
POUC2 July 1, 90-day Maximum Daily Flow: Approach 1
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |        0  35     35  65     65 100
 -----------------------+-----------------------------------
               228.000 | F     16.000      0.000      0.000
                       | O      5.00       0.00       0.00
                       | R      0.31    -999.99    -999.99
 -----------------------+-----------------------------------
     228.000   660.000 | F      8.000      0.000      8.000
                       | O      2.00       0.00       4.00
                       | R      0.25    -999.99       0.50
 -----------------------+-----------------------------------
     660.000           | F      8.000      0.000      8.000
                       | O      0.00       0.00       5.00
                       | R      0.00    -999.99       0.62
```

```
POUC2 July 1, 90-day Maximum Daily Flow: Approach 2
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |        0  35     35  65     65 100
 -----------------------+-----------------------------------
               228.000 | F      8.000      8.000      0.000
                       | O      1.00       4.00       0.00
                       | R      0.12       0.50    -999.99
 -----------------------+-----------------------------------
     228.000   660.000 | F      9.000      7.000      0.000
                       | O      2.00       4.00       0.00
                       | R      0.22       0.57    -999.99
 -----------------------+-----------------------------------
     660.000           | F      8.000      2.000      6.000
                       | O      0.00       0.00       5.00
                       | R      0.00       0.00       0.83
```

```
POUC2 July 1, 90-day Maximum Daily Flow: Approach 3
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |        0  35     35  65     65 100
 -----------------------+-----------------------------------
               228.000 | F      6.000      0.000     10.000
                       | O      0.00       0.00       5.00
                       | R      0.00    -999.99       0.50
 -----------------------+-----------------------------------
     228.000   660.000 | F     11.000      0.000      5.000
                       | O      5.00       0.00       1.00
                       | R      0.45    -999.99       0.20
 -----------------------+-----------------------------------
     660.000           | F     15.000      0.000      1.000
                       | O      4.00       0.00       1.00
                       | R      0.27    -999.99       1.00
```

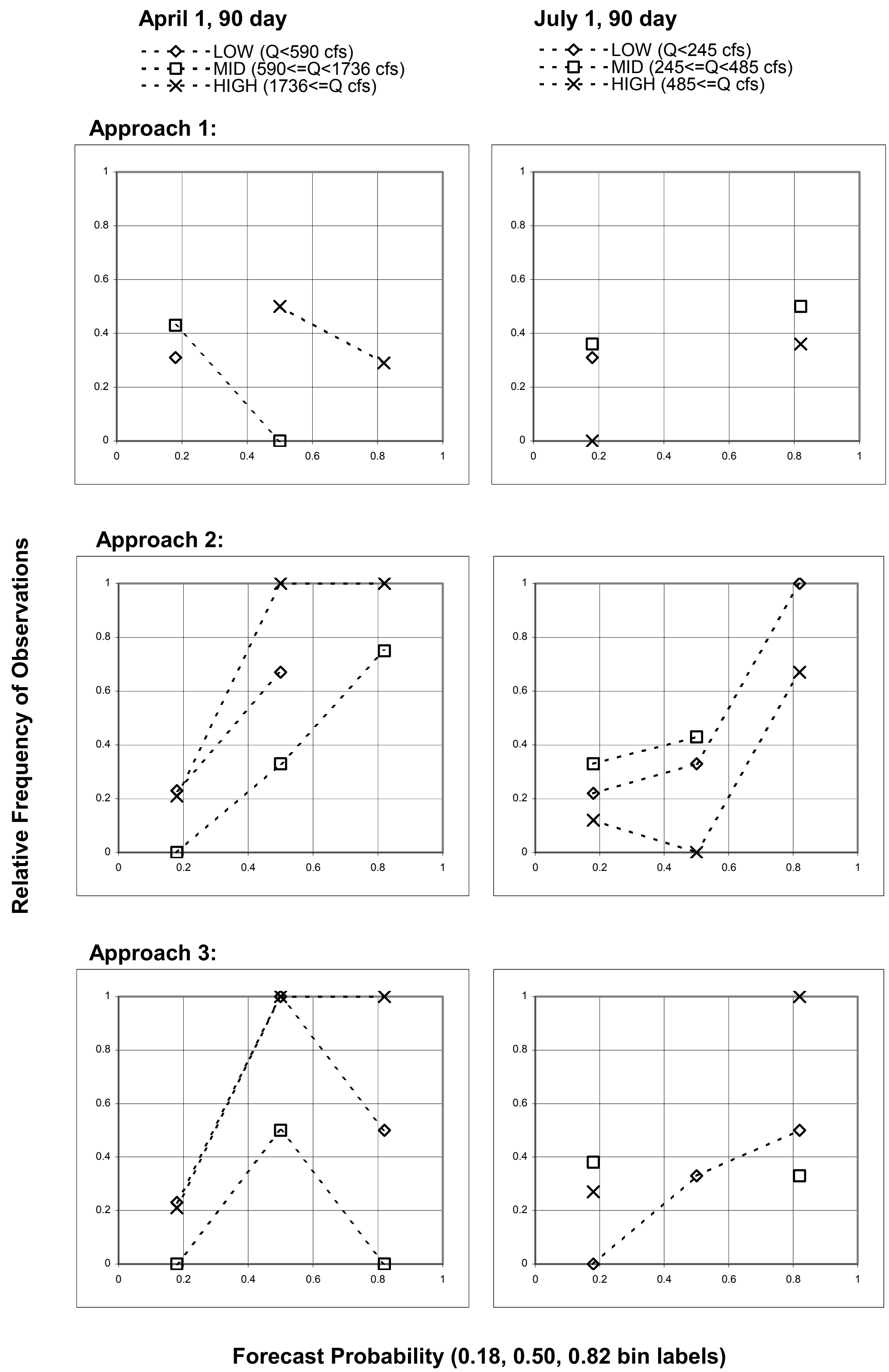


Figure D-3. Reliability Plots for GRPC2, April 1 and July 1, 90-day, Maximum Daily Flow

Table D-3a. Reliability Plot Data for GRPC2, April 1, 90-day, Maximum Daily Flow

```
GRPC2 April 1, 90-day Maximum Daily Flow: Approach 1
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
               590.000 | F     16.000      0.000      0.000
                       | O       5.00       0.00       0.00
                       | R       0.31    -999.99    -999.99
 -----------------------+-----------------------------------
      590.000  1736.000 | F     14.000      2.000      0.000
                       | O       6.00       0.00       0.00
                       | R       0.43       0.00    -999.99
 -----------------------+-----------------------------------
     1736.000           | F      0.000      2.000     14.000
                       | O       0.00       1.00       4.00
                       | R    -999.99       0.50       0.29

GRPC2 April 1, 90-day Maximum Daily Flow: Approach 2
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
               590.000 | F     13.000      3.000      0.000
                       | O       3.00       2.00       0.00
                       | R       0.23       0.67    -999.99
 -----------------------+-----------------------------------
      590.000  1736.000 | F      3.000      9.000      4.000
                       | O       0.00       3.00       3.00
                       | R       0.00       0.33       0.75
 -----------------------+-----------------------------------
     1736.000           | F     14.000      1.000      1.000
                       | O       3.00       1.00       1.00
                       | R       0.21       1.00       1.00
GRPC2 April 1, 90-day Maximum Daily Flow: Approach 3
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
               590.000 | F     13.000      1.000      2.000
                       | O       3.00       1.00       1.00
                       | R       0.23       1.00       0.50
 -----------------------+-----------------------------------
      590.000  1736.000 | F      3.000     12.000      1.000
                       | O       0.00       6.00       0.00
                       | R       0.00       0.50       0.00
 -----------------------+-----------------------------------
     1736.000           | F     14.000      1.000      1.000
                       | O       3.00       1.00       1.00
                       | R       0.21       1.00       1.00
```

Table D-3b. Reliability Plot Data for GRPC2, July 1, 90-day, Maximum Daily Flow

GRPC2 July 1, 90-day Maximum Daily Flow: Approach 1

Forecast Categories From	to <		Probability ranges from #1% to less than #2% (or to 100%) 0 35	35 65	65 100
	245.000	F	16.000	0.000	0.000
		O	5.00	0.00	0.00
		R	0.31	-999.99	-999.99
245.000	485.000	F	14.000	0.000	2.000
		O	5.00	0.00	1.00
		R	0.36	-999.99	0.50
485.000		F	2.000	0.000	14.000
		O	0.00	0.00	5.00
		R	0.00	-999.99	0.36

GRPC2 July 1, 90-day Maximum Daily Flow: Approach 2

Forecast Categories From	to <		Probability ranges from #1% to less than #2% (or to 100%) 0 35	35 65	65 100
	245.000	F	9.000	6.000	1.000
		O	2.00	2.00	1.00
		R	0.22	0.33	1.00
245.000	485.000	F	9.000	7.000	0.000
		O	3.00	3.00	0.00
		R	0.33	0.43	-999.99
485.000		F	8.000	2.000	6.000
		O	1.00	0.00	4.00
		R	0.12	0.00	0.67

GRPC2 July 1, 90-day Maximum Daily Flow: Approach 3

Forecast Categories From	to <		Probability ranges from #1% to less than #2% (or to 100%) 0 35	35 65	65 100
	245.000	F	4.000	6.000	6.000
		O	0.00	2.00	3.00
		R	0.00	0.33	0.50
245.000	485.000	F	13.000	0.000	3.000
		O	5.00	0.00	1.00
		R	0.38	-999.99	0.33
485.000		F	15.000	0.000	1.000
		O	4.00	0.00	1.00
		R	0.27	-999.99	1.00

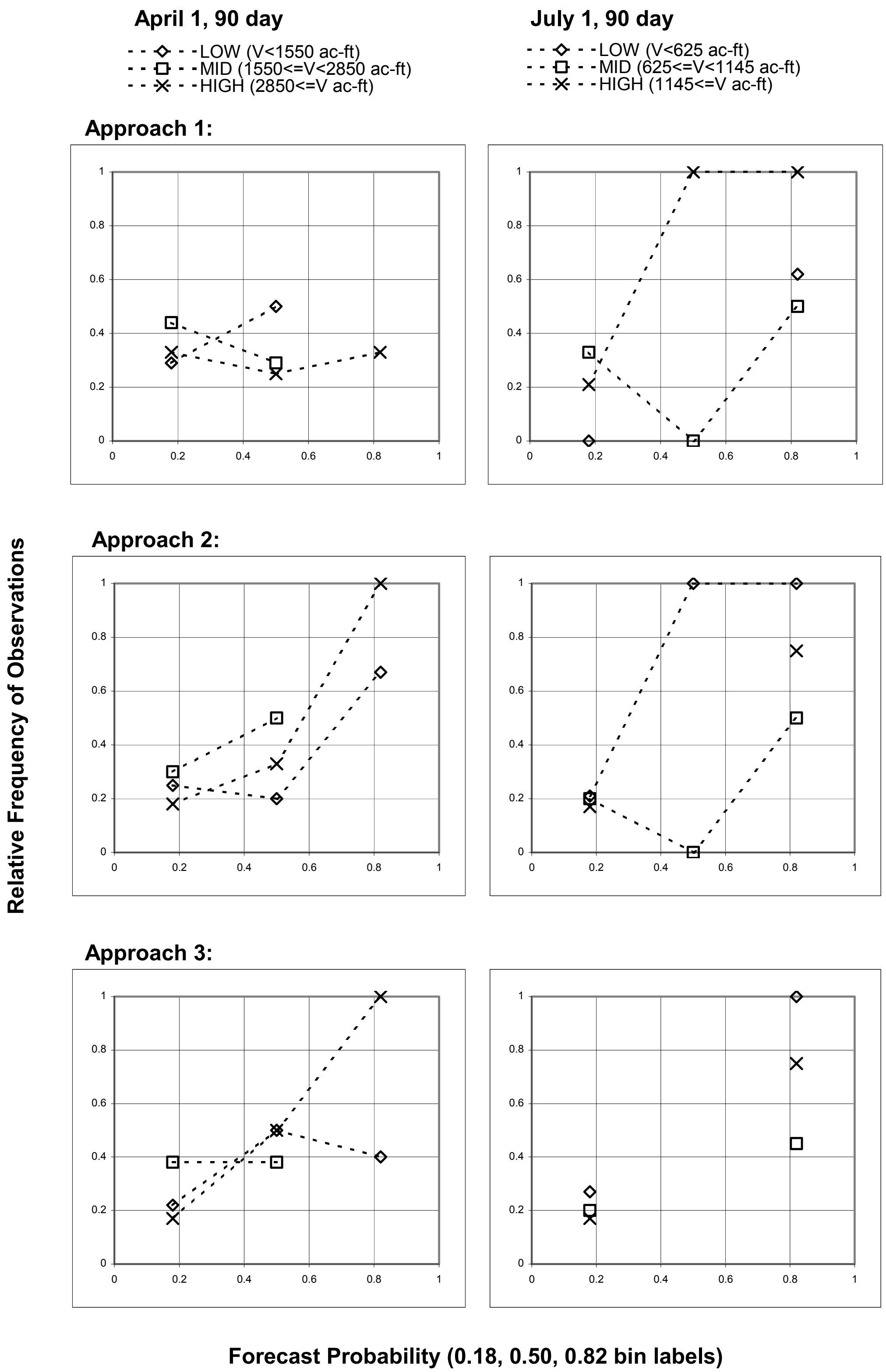


Figure D-4. Reliability Plots for FTDC2, April 1 and July 1, 90-day, Total Volume

Table D-4a. Reliability Plot Data for FTDC2, April 1, 90-day, Total Volume

```
FTDC2 April 1, 90-day Total Volume: Approach 1
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
             106000.000 | F     14.000      2.000      0.000
                        | O      4.00       1.00       0.00
                        | R      0.29       0.50    -999.99
 -----------------------+-----------------------------------
  106000.000 145000.000 | F      9.000      7.000      0.000
                        | O      4.00       2.00       0.00
                        | R      0.44       0.29    -999.99
 -----------------------+-----------------------------------
  145000.000            | F      3.000      4.000      9.000
                        | O      1.00       1.00       3.00
                        | R      0.33       0.25       0.33

FTDC2 April 1, 90-day Total Volume: Approach 2
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
             106000.000 | F      8.000      5.000      3.000
                        | O      2.00       1.00       2.00
                        | R      0.25       0.20       0.67
 -----------------------+-----------------------------------
  106000.000 145000.000 | F     10.000      6.000      0.000
                        | O      3.00       3.00       0.00
                        | R      0.30       0.50    -999.99
 -----------------------+-----------------------------------
  145000.000            | F     11.000      3.000      2.000
                        | O      2.00       1.00       2.00
                        | R      0.18       0.33       1.00

FTDC2 April 1, 90-day Total Volume: Approach 3
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
             106000.000 | F      9.000      2.000      5.000
                        | O      2.00       1.00       2.00
                        | R      0.22       0.50       0.40
 -----------------------+-----------------------------------
  106000.000 145000.000 | F      8.000      8.000      0.000
                        | O      3.00       3.00       0.00
                        | R      0.38       0.38    -999.99
 -----------------------+-----------------------------------
  145000.000            | F     12.000      2.000      2.000
                        | O      2.00       1.00       2.00
                        | R      0.17       0.50       1.00
```

Table D-4b. Reliability Plot Data for FTDC2, July 1, 90-day, Total Volume

FTDC2 July 1, 90-day Total Volume: Approach 1

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	41000.000	F	8.000	0.000	8.000
		O	0.00	0.00	5.00
		R	0.00	-999.99	0.62
41000.000	79000.000	F	9.000	1.000	6.000
		O	3.00	0.00	3.00
		R	0.33	0.00	0.50
79000.000		F	14.000	1.000	1.000
		O	3.00	1.00	1.00
		R	0.21	1.00	1.00

FTDC2 July 1, 90-day Total Volume: Approach 2

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	41000.000	F	14.000	1.000	1.000
		O	3.00	1.00	1.00
		R	0.21	1.00	1.00
41000.000	79000.000	F	5.000	1.000	10.000
		O	1.00	0.00	5.00
		R	0.20	0.00	0.50
79000.000		F	12.000	0.000	4.000
		O	2.00	0.00	3.00
		R	0.17	-999.99	0.75

FTDC2 July 1, 90-day Total Volume: Approach 3

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	41000.000	F	15.000	0.000	1.000
		O	4.00	0.00	1.00
		R	0.27	-999.99	1.00
41000.000	79000.000	F	5.000	0.000	11.000
		O	1.00	0.00	5.00
		R	0.20	-999.99	0.45
79000.000		F	12.000	0.000	4.000
		O	2.00	0.00	3.00
		R	0.17	-999.99	0.75

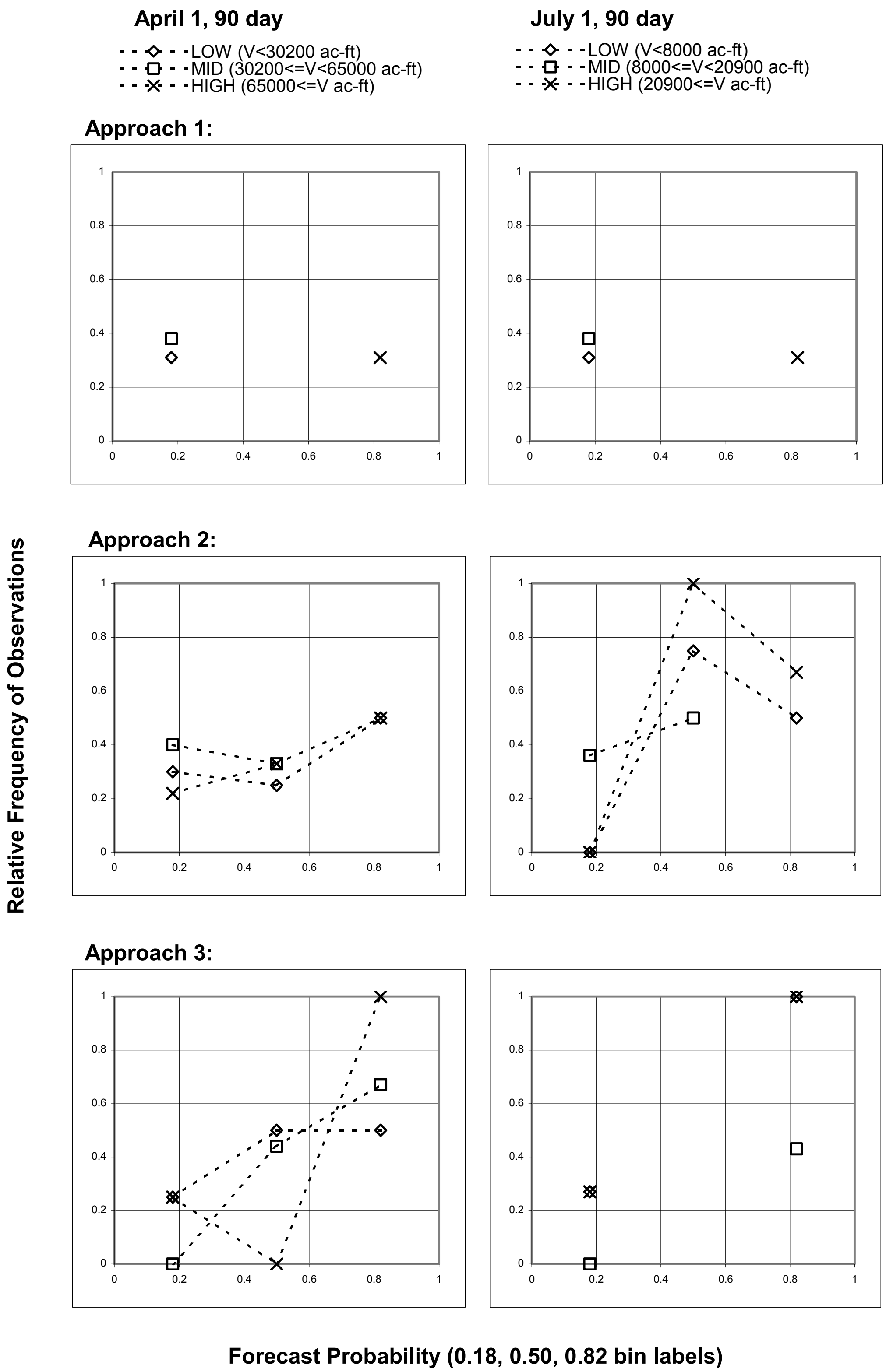


Figure D-5. Reliability Plots for POUC2, April 1 and July 1, 90-day, Total Volume

Table D-5a. Reliability Plot Data for POUC2, April 1, 90-day, Total Volume

```
POUC2 April 1, 90-day Total Volume: Approach 1
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |        0  35     35  65     65 100
 -----------------------+----------------------------------
             30200.000 | F     16.000      0.000      0.000
                       | O       5.00       0.00       0.00
                       | R       0.31    -999.99    -999.99
 -----------------------+----------------------------------
   30200.000  65000.000 | F     16.000      0.000      0.000
                       | O       6.00       0.00       0.00
                       | R       0.38    -999.99    -999.99
 -----------------------+----------------------------------
   65000.000            | F      0.000      0.000     16.000
                       | O       0.00       0.00       5.00
                       | R    -999.99    -999.99       0.31
```

```
POUC2 April 1, 90-day Total Volume: Approach 2
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |        0  35     35  65     65 100
 -----------------------+----------------------------------
             30200.000 | F     10.000      4.000      2.000
                       | O       3.00       1.00       1.00
                       | R       0.30       0.25       0.50
 -----------------------+----------------------------------
   30200.000  65000.000 | F     10.000      6.000      0.000
                       | O       4.00       2.00       0.00
                       | R       0.40       0.33    -999.99
 -----------------------+----------------------------------
   65000.000            | F      9.000      3.000      4.000
                       | O       2.00       1.00       2.00
                       | R       0.22       0.33       0.50
```

```
POUC2 April 1, 90-day Total Volume: Approach 3
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |        0  35     35  65     65 100
 -----------------------+----------------------------------
             30200.000 | F     12.000      2.000      2.000
                       | O       3.00       1.00       1.00
                       | R       0.25       0.50       0.50
 -----------------------+----------------------------------
   30200.000  65000.000 | F      4.000      9.000      3.000
                       | O       0.00       4.00       2.00
                       | R       0.00       0.44       0.67
 -----------------------+----------------------------------
   65000.000            | F     12.000      2.000      2.000
                       | O       3.00       0.00       2.00
                       | R       0.25       0.00       1.00
```

Table D-5b. Reliability Plot Data for POUC2, April 1, 90-day, Total Volume

POUC2 July 1, 90-day Total Volume: Approach 1

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	8000.000	F	16.000	0.000	0.000
		O	5.00	0.00	0.00
		R	0.31	-999.99	-999.99
8000.000	20900.000	F	16.000	0.000	0.000
		O	6.00	0.00	0.00
		R	0.38	-999.99	-999.99
20900.000		F	0.000	0.000	16.000
		O	0.00	0.00	5.00
		R	-999.99	-999.99	0.31

POUC2 July 1, 90-day Total Volume: Approach 2

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	8000.000	F	8.000	4.000	4.000
		O	0.00	3.00	2.00
		R	0.00	0.75	0.50
8000.000	20900.000	F	14.000	2.000	0.000
		O	5.00	1.00	0.00
		R	0.36	0.50	-999.99
20900.000		F	9.000	1.000	6.000
		O	0.00	1.00	4.00
		R	0.00	1.00	0.67

POUC2 July 1, 90-day Total Volume: Approach 3

Forecast Categories | Probability ranges from #1% to less than #2% (or to 100%)

From	to <		0 35	35 65	65 100
	8000.000	F	15.000	0.000	1.000
		O	4.00	0.00	1.00
		R	0.27	-999.99	1.00
8000.000	20900.000	F	2.000	0.000	14.000
		O	0.00	0.00	6.00
		R	0.00	-999.99	0.43
20900.000		F	15.000	0.000	1.000
		O	4.00	0.00	1.00
		R	0.27	-999.99	1.00

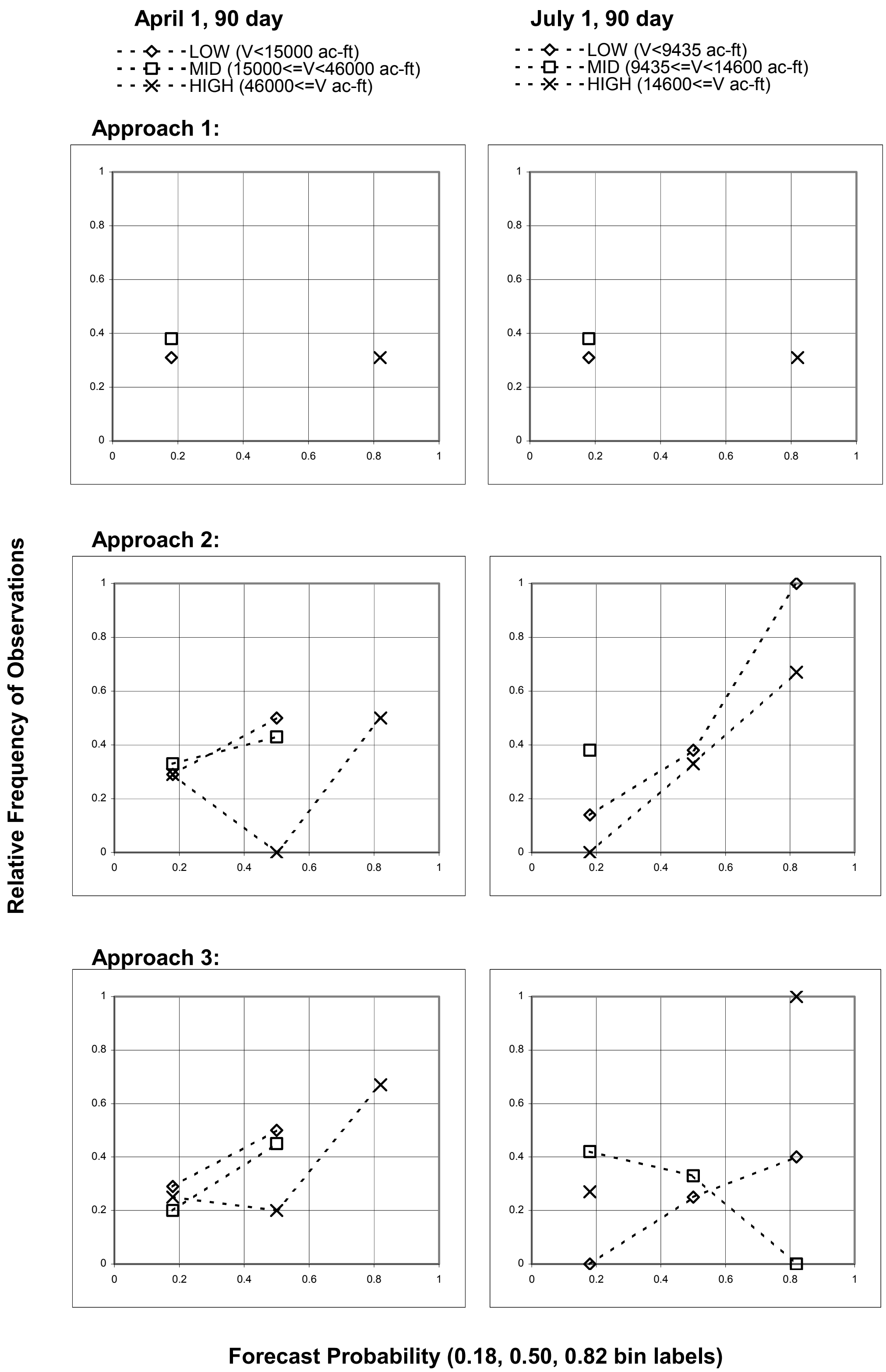


Figure D-6. Reliability Plots for GRPC2, April 1 and July 1, 90-day, Total Volume

Table D-6a. Reliability Plot Data for GRPC2, April 1, 90-day, Total Volume

```
GRPC2 April 1, 90-day Total Volume: Approach 1
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
              15000.000 | F     16.000      0.000      0.000
                        | O      5.00       0.00       0.00
                        | R      0.31    -999.99    -999.99
 -----------------------+-----------------------------------
   15000.000  46000.000 | F     16.000      0.000      0.000
                        | O      6.00       0.00       0.00
                        | R      0.38    -999.99    -999.99
 -----------------------+-----------------------------------
   46000.000            | F      0.000      0.000     16.000
                        | O      0.00       0.00       5.00
                        | R   -999.99    -999.99       0.31
```

```
GRPC2 April 1, 90-day Total Volume: Approach 2
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
              15000.000 | F     14.000      2.000      0.000
                        | O      4.00       1.00       0.00
                        | R      0.29       0.50    -999.99
 -----------------------+-----------------------------------
   15000.000  46000.000 | F      9.000      7.000      0.000
                        | O      3.00       3.00       0.00
                        | R      0.33       0.43    -999.99
 -----------------------+-----------------------------------
   46000.000            | F      7.000      3.000      6.000
                        | O      2.00       0.00       3.00
                        | R      0.29       0.00       0.50
```

```
GRPC2 April 1, 90-day Total Volume: Approach 3
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |         0  35     35  65     65 100
 -----------------------+-----------------------------------
              15000.000 | F     14.000      2.000      0.000
                        | O      4.00       1.00       0.00
                        | R      0.29       0.50    -999.99
 -----------------------+-----------------------------------
   15000.000  46000.000 | F      5.000     11.000      0.000
                        | O      1.00       5.00       0.00
                        | R      0.20       0.45    -999.99
 -----------------------+-----------------------------------
   46000.000            | F      8.000      5.000      3.000
                        | O      2.00       1.00       2.00
                        | R      0.25       0.20       0.67
```

Table D-6b. Reliability Plot Data for GRPC2, July 1, 90-day, Total Volume

```
GRPC2 July 1, 90-day Total Volume: Approach 1
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |          0  35     35  65     65 100
 -----------------------+-----------------------------------
              9435.000 | F     16.000      0.000      0.000
                       | O      5.00       0.00       0.00
                       | R      0.31    -999.99    -999.99
 -----------------------+-----------------------------------
    9435.000  14600.000 | F     16.000      0.000      0.000
                       | O      6.00       0.00       0.00
                       | R      0.38    -999.99    -999.99
 -----------------------+-----------------------------------
   14600.000            | F      0.000      0.000     16.000
                       | O      0.00       0.00       5.00
                       | R   -999.99    -999.99       0.31
```

```
GRPC2 July 1, 90-day Total Volume: Approach 2
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |          0  35     35  65     65 100
 -----------------------+-----------------------------------
              9435.000 | F      7.000      8.000      1.000
                       | O      1.00       3.00       1.00
                       | R      0.14       0.38       1.00
 -----------------------+-----------------------------------
    9435.000  14600.000 | F     16.000      0.000      0.000
                       | O      6.00       0.00       0.00
                       | R      0.38    -999.99    -999.99
 -----------------------+-----------------------------------
   14600.000            | F      7.000      3.000      6.000
                       | O      0.00       1.00       4.00
                       | R      0.00       0.33       0.67
```

```
GRPC2 July 1, 90-day Total Volume: Approach 3
    Forecast Categories | Probability ranges from #1% to less than #2% ( or to 100% )
       From       to <  |          0  35     35  65     65 100
 -----------------------+-----------------------------------
              9435.000 | F      2.000      4.000     10.000
                       | O      0.00       1.00       4.00
                       | R      0.00       0.25       0.40
 -----------------------+-----------------------------------
    9435.000  14600.000 | F     12.000      3.000      1.000
                       | O      5.00       1.00       0.00
                       | R      0.42       0.33       0.00
 -----------------------+-----------------------------------
   14600.000            | F     15.000      0.000      1.000
                       | O      4.00       0.00       1.00
                       | R      0.27    -999.99       1.00
```

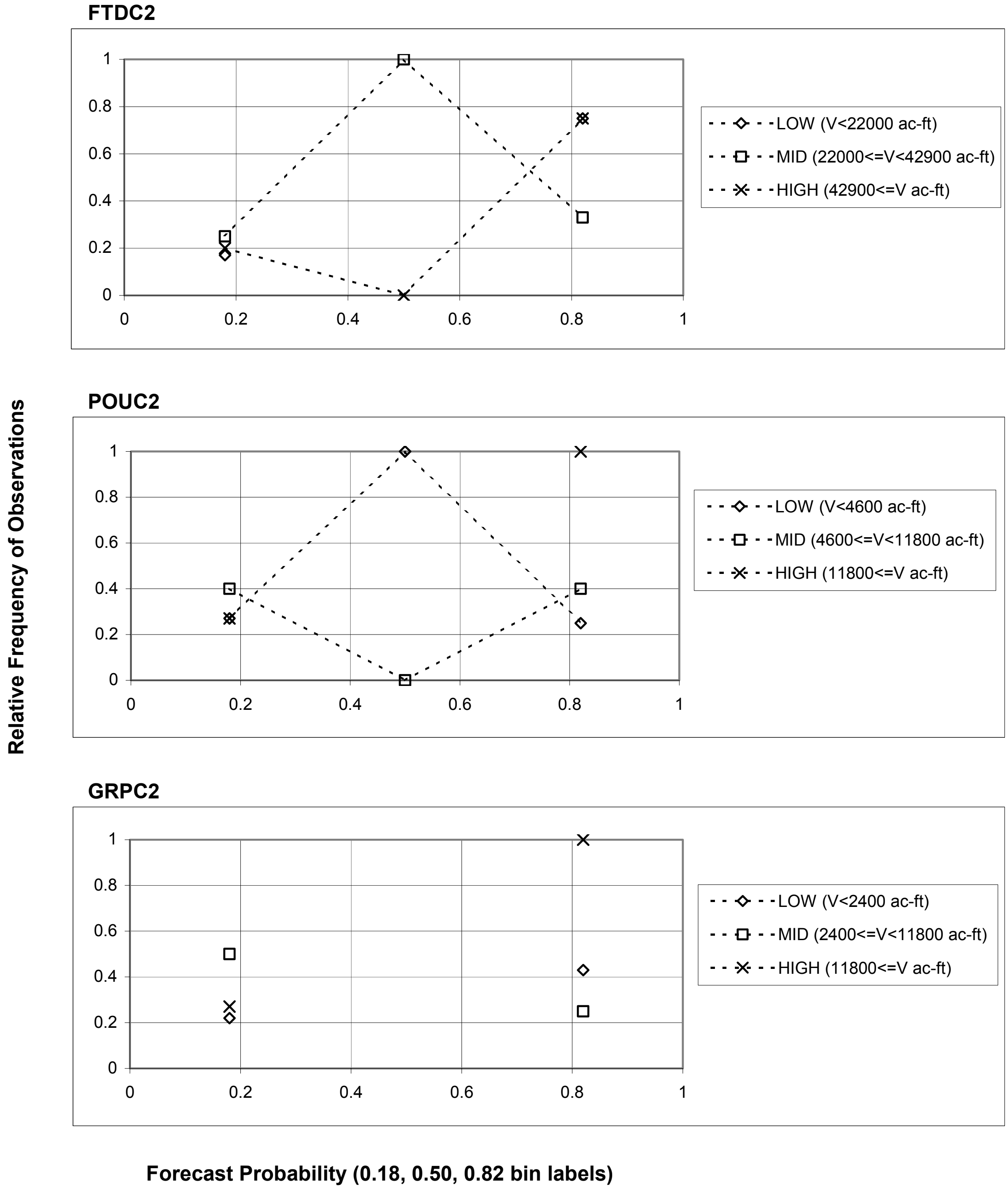


Figure D-7. Reliability Plots for Approach 3, July 1, 30-day Total Volume

Table D-7. Reliability Plot Data for Approach 3, July 1, 30-day Total Volume

FTDC2 July 1, 30-day Total Volume: Approach 3

Forecast Categories From	Forecast Categories to <	Probability ranges from #1% to less than #2% (or to 100%)	0 35	35 65	65 100
	22000.000	F	12.000	0.000	4.000
		O	2.00	0.00	3.00
		R	0.17	-999.99	0.75
22000.000	42900.000	F	8.000	2.000	6.000
		O	2.00	2.00	2.00
		R	0.25	1.00	0.33
42900.000		F	10.000	2.000	4.000
		O	2.00	0.00	3.00
		R	0.20	0.00	0.75

POUC2 July 1, 30-day Total Volume: Approach 3

Forecast Categories From	Forecast Categories to <	Probability ranges from #1% to less than #2% (or to 100%)	0 35	35 65	65 100
	4600.000	F	11.000	1.000	4.000
		O	3.00	1.00	1.00
		R	0.27	1.00	0.25
4600.000	11800.000	F	5.000	1.000	10.000
		O	2.00	0.00	4.00
		R	0.40	0.00	0.40
11800.000		F	15.000	0.000	1.000
		O	4.00	0.00	1.00
		R	0.27	-999.99	1.00

GRPC2 July 1, 30-day Total Volume: Approach 3

Forecast Categories From	Forecast Categories to <	Probability ranges from #1% to less than #2% (or to 100%)	0 35	35 65	65 100
	2400.000	F	9.000	0.000	7.000
		O	2.00	0.00	3.00
		R	0.22	-999.99	0.43
2400.000	5900.000	F	8.000	0.000	8.000
		O	4.00	0.00	2.00
		R	0.50	-999.99	0.25
5900.000		F	15.000	0.000	1.000
		O	4.00	0.00	1.00
		R	0.27	-999.99	1.00

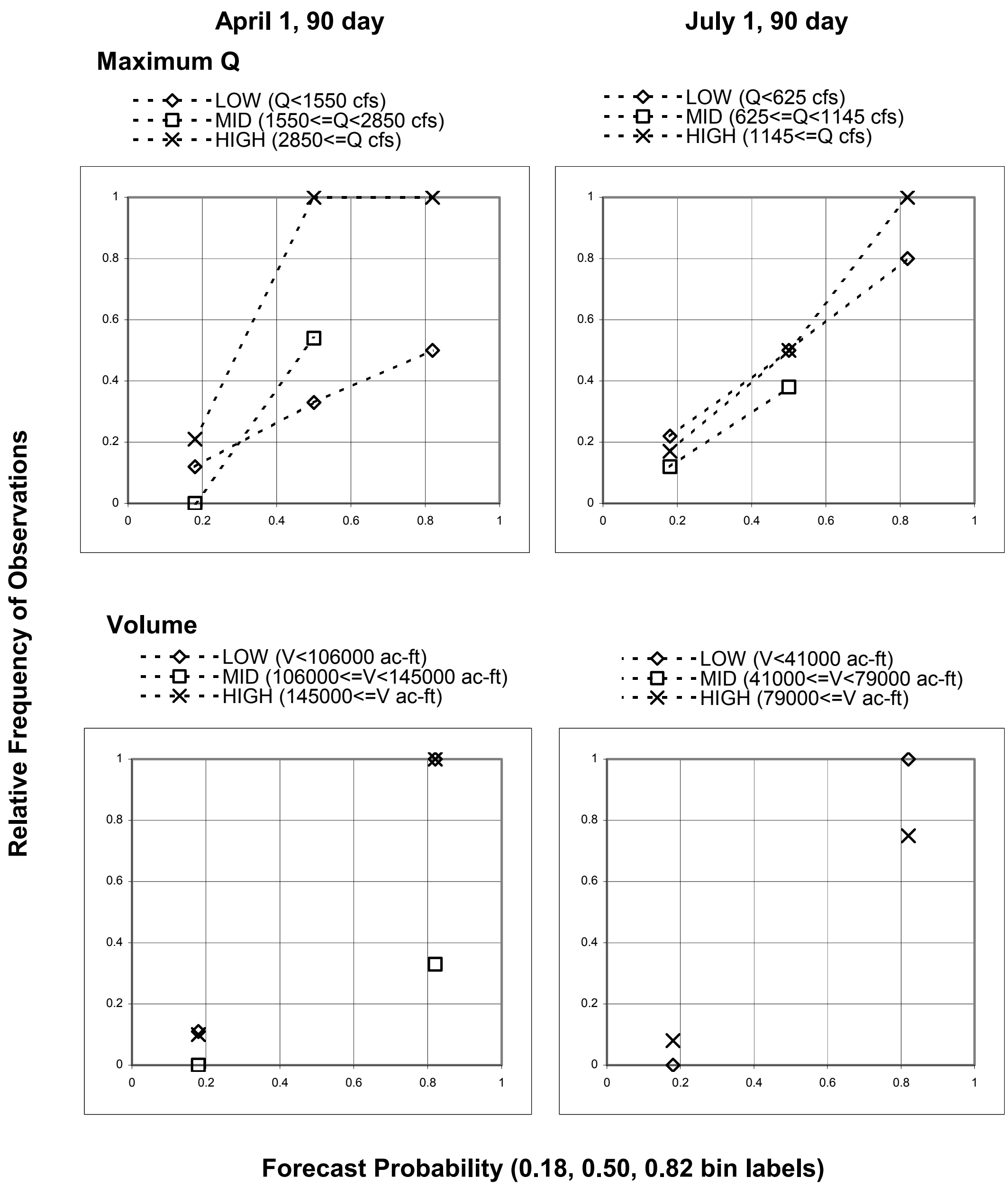


Figure D-8. Reliability Plots for Approach 3, FTDC2, April 1 and July 1, 90-day, Maximum Flow and Total Volume—Simulated Time Series as Observation

Table D-8. Reliability Plot Data for Approach 3, FTDC2, April 1 and July 1, 90-day, Maximum Flow and Total Volume—Simulated Time Series as Observation

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 3

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	1550.000	F	8.000	6.000	2.000
		O	1.00	2.00	1.00
		R	0.12	0.33	0.50
1550.000	2850.000	F	3.000	13.000	0.000
		O	0.00	7.00	0.00
		R	0.00	0.54	-999.99
2850.000		F	14.000	1.000	1.000
		O	3.00	1.00	1.00
		R	0.21	1.00	1.00

FTDC2 July 1, 90-day Maximum Daily Flow: Approach 3

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	625.000	F	9.000	0.000	7.000
		O	1.00	0.00	7.00
		R	0.11	-999.99	1.00
625.000	1145.000	F	13.000	0.000	3.000
		O	0.00	0.00	1.00
		R	0.00	-999.99	0.33
1145.000		F	10.000	0.000	6.000
		O	1.00	0.00	6.00
		R	0.10	-999.99	1.00

FTDC2 April 1, 90-day Total Volume: Approach 3

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	106000.000	F	9.000	2.000	5.000
		O	2.00	1.00	4.00
		R	0.22	0.50	0.80
106000.000	145000.000	F	8.000	8.000	0.000
		O	1.00	3.00	0.00
		R	0.12	0.38	-999.99
145000.000		F	12.000	2.000	2.000
		O	2.00	1.00	2.00
		R	0.17	0.50	1.00

FTDC2 July 1, 90-day Total Volume: Approach 3

Forecast Categories		Probability ranges from #1% to less than #2% (or to 100%)			
From	to <		0 35	35 65	65 100
	41000.000	F	15.000	0.000	1.000
		O	0.00	0.00	1.00
		R	0.00	-999.99	1.00
41000.000	79000.000	F	5.000	0.000	11.000
		O	1.00	0.00	10.00
		R	0.20	-999.99	0.91
79000.000		F	12.000	0.000	4.000
		O	1.00	0.00	3.00
		R	0.08	-999.99	0.75

APPENDIX E

Verification Statistics: Discrimination Plots

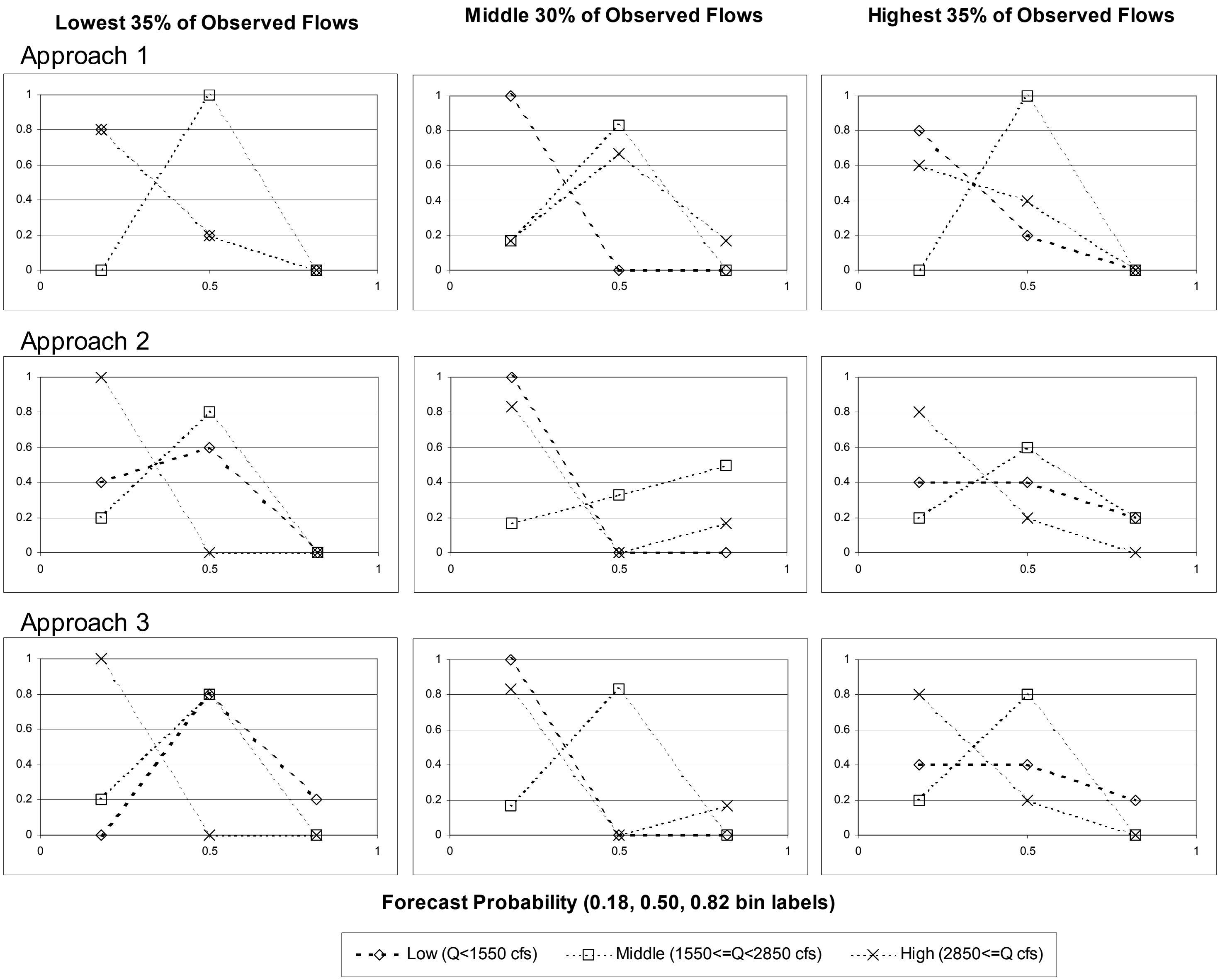


Figure E-1. Discrimination Plots for FTDC2, April 1, 90-day, Maximum Daily Flow

Discrimination table descriptions

The data in the following tables are extracted from the *.iwk files output by probVS for the discrimination statistic. The essential information from the tables is included in each table; the full table output from the probVS program is shown below. The data corresponding to the first row of plots in ***Figure E-1*** is used as an example. The left column contains information about the observed flows. It gives the flow range in the first row (<1550, 1550-2850, and >2850 in this case) and the number of observations within each flow range at the end of the second row (5, 6, and 5, respectively). The second, third, and fourth column correspond to different forecast probability ranges (0-35%, 35-65%, and 65-100%). When the observation occurred in a given range (the rows), the table shows the number of forecasts within a certain probability range for each of the three flow levels (F0, F1, and F2). The corresponding fraction of times this range was forecasted at the given probability level is computed and listed.

The plots in the first row of ***Figure E-1*** are generated as follows. First, each plot is generated using data from one of the three rows. In a given plot, the low flow range data is plotted using the F0 data, the middle flow range using the F1 data, and the high flow range using the F2 data. Thus, in the middle plot (for the middle flow range), the high flow line uses the data (0.17, 0.67, 0.17).

A set of tables is included corresponding to each of the sets of discrimination plots.

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 1

```
| For all forecasts where the obs occurred from C1 to <C2, the probability of the forecast was:
                                 |
      Observations               |    0% to < 35% |   35% to < 65% |   65% to <100%
      From C1  to  < C2          |----------------+----------------+---------------
           %     # Obs           | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
   ------------------------------+----------------+----------------+---------------
                1550.000         |    4    0    4 |    1    5    1 |    0    0    0
           70          5         | 0.80 0.00 0.80 | 0.20 1.00 0.20 | 0.00 0.00 0.00
   ------------------------------+----------------+----------------+---------------
      1550.000  2850.000         |    6    1    1 |    0    5    4 |    0    0    1
           30          6         | 1.00 0.17 0.17 | 0.00 0.83 0.67 | 0.00 0.00 0.17
   ------------------------------+----------------+----------------+---------------
      2850.000                   |    4    0    3 |    1    5    2 |    0    0    0
            0          5         | 0.80 0.00 0.60 | 0.20 1.00 0.40 | 0.00 0.00 0.00

                                 Where the following applies

                                      |      From      to <
                                 -----+--------------------
                                  F0  |            1550.000
                                  F1  |  1550.000  2850.000
                                  F2  |  2850.000
```

Table E-1. Discrimination Plot Data for FTDC2, April 1, 90-day, Maximum Daily Flow

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 1

Observations From C1 %	to < C2 # Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	1550.000	4	0	4	1	5	1	0	0	0
70	5	0.80	0.00	0.80	0.20	1.00	0.20	0.00	0.00	0.00
1550.000	2850.000	6	1	1	0	5	4	0	0	1
30	6	1.00	0.17	0.17	0.00	0.83	0.67	0.00	0.00	0.17
2850.000		4	0	3	1	5	2	0	0	0
0	5	0.80	0.00	0.60	0.20	1.00	0.40	0.00	0.00	0.00

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 2

Observations From C1 %	to < C2 # Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	1550.000	2	1	5	3	4	0	0	0	0
70	5	0.40	0.20	1.00	0.60	0.80	0.00	0.00	0.00	0.00
1550.000	2850.000	6	1	5	0	2	0	0	3	1
30	6	1.00	0.17	0.83	0.00	0.33	0.00	0.00	0.50	0.17
2850.000		2	1	4	2	3	1	1	1	0
0	5	0.40	0.20	0.80	0.40	0.60	0.20	0.20	0.20	0.00

FTDC2 April 1, 90-day Maximum Daily Flow: Approach 3

Observations From C1 %	to < C2 # Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	1550.000	0	1	5	4	4	0	1	0	0
70	5	0.00	0.20	1.00	0.80	0.80	0.00	0.20	0.00	0.00
1550.000	2850.000	6	1	5	0	5	0	0	0	1
30	6	1.00	0.17	0.83	0.00	0.83	0.00	0.00	0.00	0.17
2850.000		2	1	4	2	4	1	1	0	0
0	5	0.40	0.20	0.80	0.40	0.80	0.20	0.20	0.00	0.00

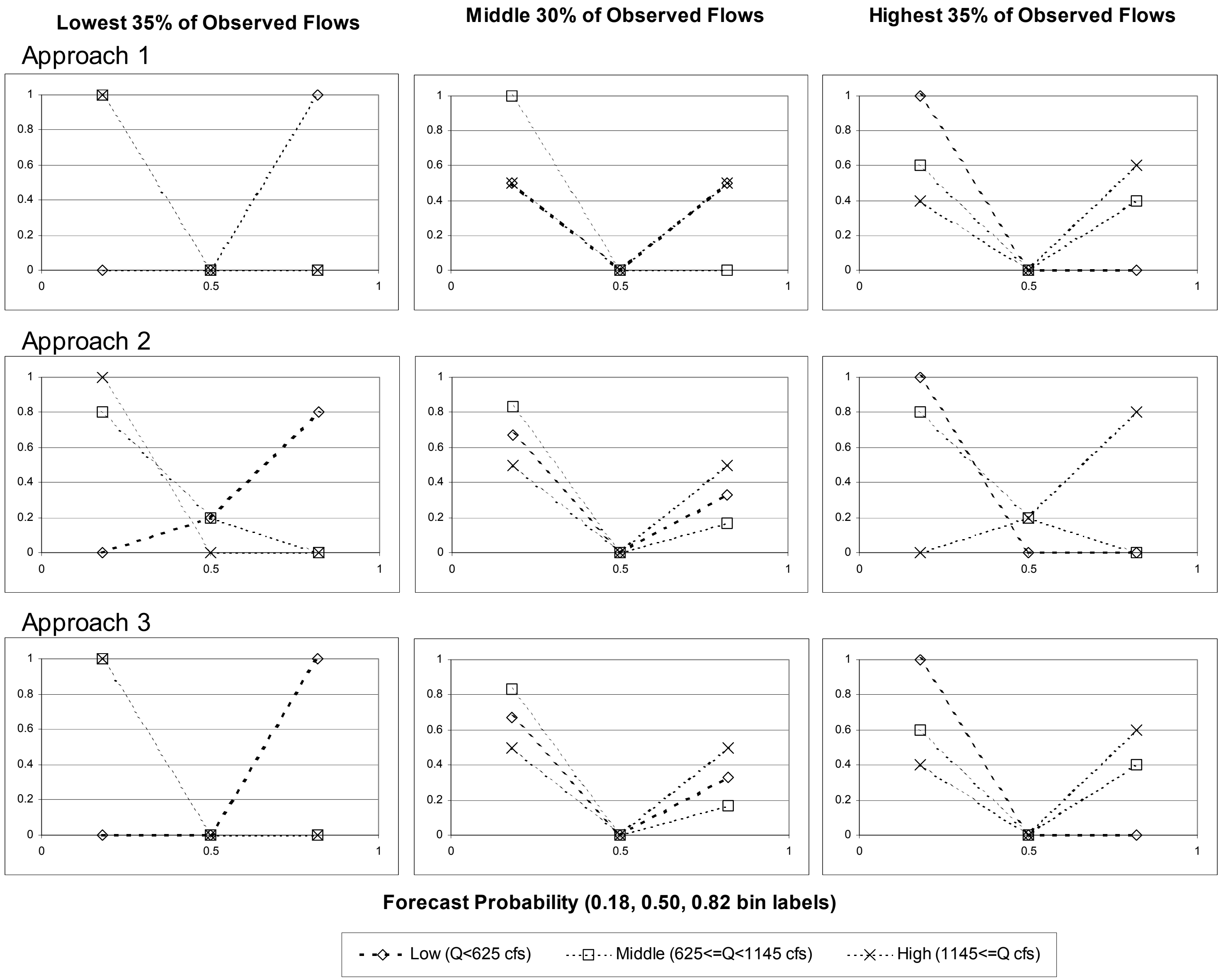


Figure E-2. Discrimination Plots for FTDC2, July 1, 90-day, Maximum Daily Flow

Table E-2. Discrimination Plot Data for FTDC2, July 1, 90-day, Maximum Daily Flow

```
FTDC2 July 1, 90-day Maximum Daily Flow: Approach 1
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    625.000 |    0    5    5 |    0    0    0 |    5    0    0
                69        5 | 0.00 1.00 1.00 | 0.00 0.00 0.00 | 1.00 0.00 0.00
       ---------------------+----------------+----------------+---------------
          625.000  1145.000 |    3    6    3 |    0    0    0 |    3    0    3
                31        6 | 0.50 1.00 0.50 | 0.00 0.00 0.00 | 0.50 0.00 0.50
       ---------------------+----------------+----------------+---------------
         1145.000           |    5    3    2 |    0    0    0 |    0    2    3
                 0        5 | 1.00 0.60 0.40 | 0.00 0.00 0.00 | 0.00 0.40 0.60

FTDC2 July 1, 90-day Maximum Daily Flow: Approach 2
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    625.000 |    0    4    5 |    1    1    0 |    4    0    0
                69        5 | 0.00 0.80 1.00 | 0.20 0.20 0.00 | 0.80 0.00 0.00
       ---------------------+----------------+----------------+---------------
          625.000  1145.000 |    4    5    3 |    0    0    0 |    2    1    3
                31        6 | 0.67 0.83 0.50 | 0.00 0.00 0.00 | 0.33 0.17 0.50
       ---------------------+----------------+----------------+---------------
         1145.000           |    5    4    0 |    0    1    1 |    0    0    4
                 0        5 | 1.00 0.80 0.00 | 0.00 0.20 0.20 | 0.00 0.00 0.80

FTDC2 July 1, 90-day Maximum Daily Flow: Approach 3
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    625.000 |    0    5    5 |    0    0    0 |    5    0    0
                69        5 | 0.00 1.00 1.00 | 0.00 0.00 0.00 | 1.00 0.00 0.00
       ---------------------+----------------+----------------+---------------
          625.000  1145.000 |    4    5    3 |    0    0    0 |    2    1    3
                31        6 | 0.67 0.83 0.50 | 0.00 0.00 0.00 | 0.33 0.17 0.50
       ---------------------+----------------+----------------+---------------
         1145.000           |    5    3    2 |    0    0    0 |    0    2    3
                 0        5 | 1.00 0.60 0.40 | 0.00 0.00 0.00 | 0.00 0.40 0.60
```

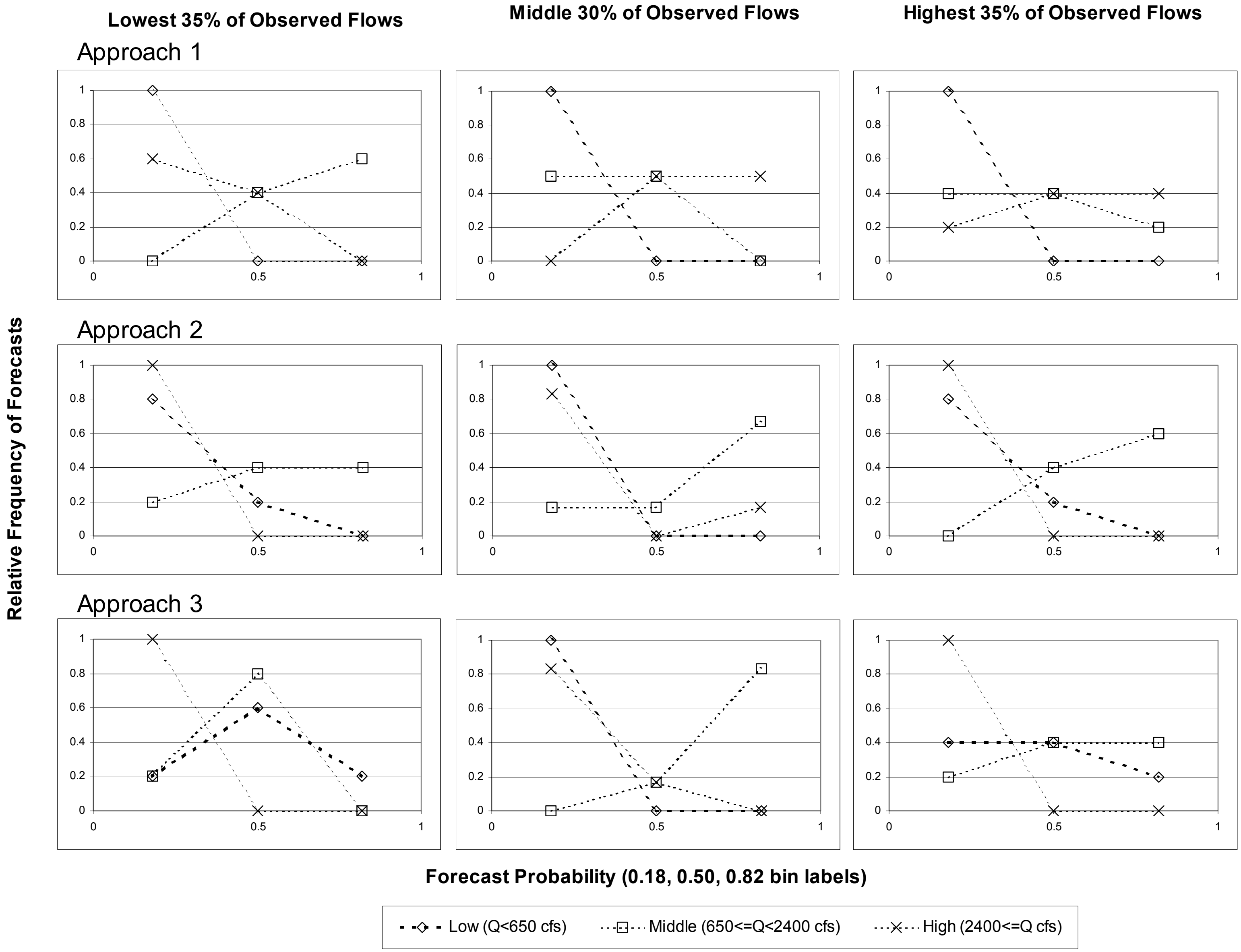


Figure E-3. Discrimination Plots for POUC2, April 1, 90-day, Maximum Daily Flow

Table E-3. Discrimination Plot Data for POUC2, April 1, 90-day, Maximum Daily Flow

POUC2 April 1, 90-day Maximum Daily Flow: Approach 1

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	650.000	5	0	3	0	2	2	0	3	0
70	5	1.00	0.00	0.60	0.00	0.40	0.40	0.00	0.60	0.00
650.000	2400.000	6	3	0	0	3	3	0	0	3
30	6	1.00	0.50	0.00	0.00	0.50	0.50	0.00	0.00	0.50
2400.000		5	2	1	0	2	2	0	1	2
0	5	1.00	0.40	0.20	0.00	0.40	0.40	0.00	0.20	0.40

POUC2 April 1, 90-day Maximum Daily Flow: Approach 2

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	650.000	4	1	5	1	2	0	0	2	0
70	5	0.80	0.20	1.00	0.20	0.40	0.00	0.00	0.40	0.00
650.000	2400.000	6	1	5	0	1	0	0	4	1
30	6	1.00	0.17	0.83	0.00	0.17	0.00	0.00	0.67	0.17
2400.000		4	0	5	1	2	0	0	3	0
0	5	0.80	0.00	1.00	0.20	0.40	0.00	0.00	0.60	0.00

POUC2 April 1, 90-day Maximum Daily Flow: Approach 3

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	650.000	1	1	5	3	4	0	1	0	0
70	5	0.20	0.20	1.00	0.60	0.80	0.00	0.20	0.00	0.00
650.000	2400.000	6	0	5	0	1	1	0	5	0
30	6	1.00	0.00	0.83	0.00	0.17	0.17	0.00	0.83	0.00
2400.000		2	1	5	2	2	0	1	2	0
0	5	0.40	0.20	1.00	0.40	0.40	0.00	0.20	0.40	0.00

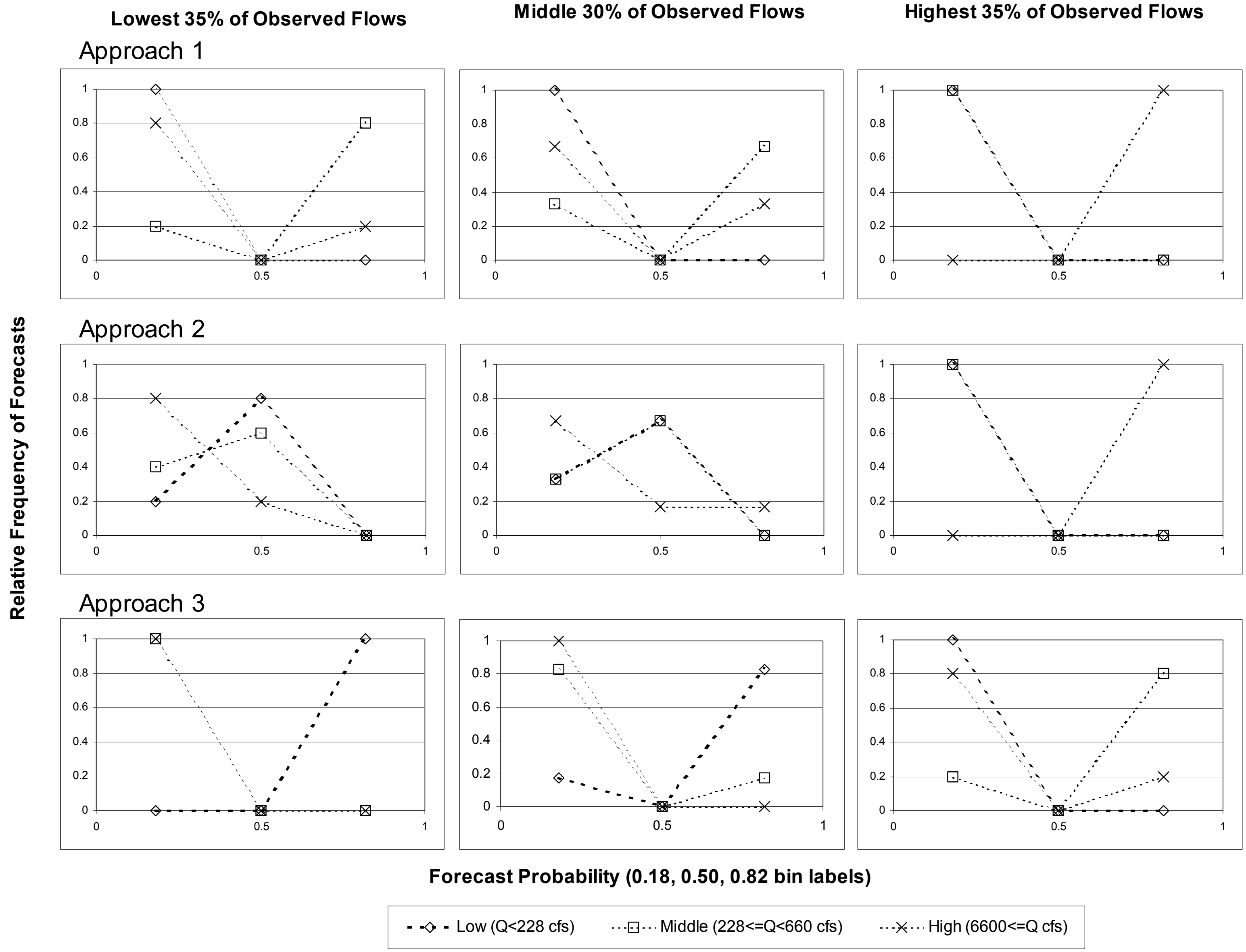


Figure E-4. Discrimination Plots for POUC2, July 1, 90-day, Maximum Daily Flow

Table E-4. Discrimination Plot Data for POUC2, July 1, 90-day, Maximum Daily Flow

```
POUC2 July 1, 90-day Maximum Daily Flow: Approach 1
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    228.000 |    5    1    4 |    0    0    0 |    0    4    1
                70        5 | 1.00 0.20 0.80 | 0.00 0.00 0.00 | 0.00 0.80 0.20
       ---------------------+----------------+----------------+---------------
          228.000   660.000 |    6    2    4 |    0    0    0 |    0    4    2
                30        6 | 1.00 0.33 0.67 | 0.00 0.00 0.00 | 0.00 0.67 0.33
       ---------------------+----------------+----------------+---------------
          660.000           |    5    5    0 |    0    0    0 |    0    0    5
                 0        5 | 1.00 1.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 1.00

POUC2 July 1, 90-day Maximum Daily Flow: Approach 2
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    228.000 |    1    2    4 |    4    3    1 |    0    0    0
                70        5 | 0.20 0.40 0.80 | 0.80 0.60 0.20 | 0.00 0.00 0.00
       ---------------------+----------------+----------------+---------------
          228.000   660.000 |    2    2    4 |    4    4    1 |    0    0    1
                30        6 | 0.33 0.33 0.67 | 0.67 0.67 0.17 | 0.00 0.00 0.17
       ---------------------+----------------+----------------+---------------
          660.000           |    5    5    0 |    0    0    0 |    0    0    5
                 0        5 | 1.00 1.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 1.00

POUC2 July 1, 90-day Maximum Daily Flow: Approach 3
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    228.000 |    0    5    5 |    0    0    0 |    5    0    0
                70        5 | 0.00 1.00 1.00 | 0.00 0.00 0.00 | 1.00 0.00 0.00
       ---------------------+----------------+----------------+---------------
          228.000   660.000 |    1    5    6 |    0    0    0 |    5    1    0
                30        6 | 0.17 0.83 1.00 | 0.00 0.00 0.00 | 0.83 0.17 0.00
       ---------------------+----------------+----------------+---------------
          660.000           |    5    1    4 |    0    0    0 |    0    4    1
                 0        5 | 1.00 0.20 0.80 | 0.00 0.00 0.00 | 0.00 0.80 0.20
```

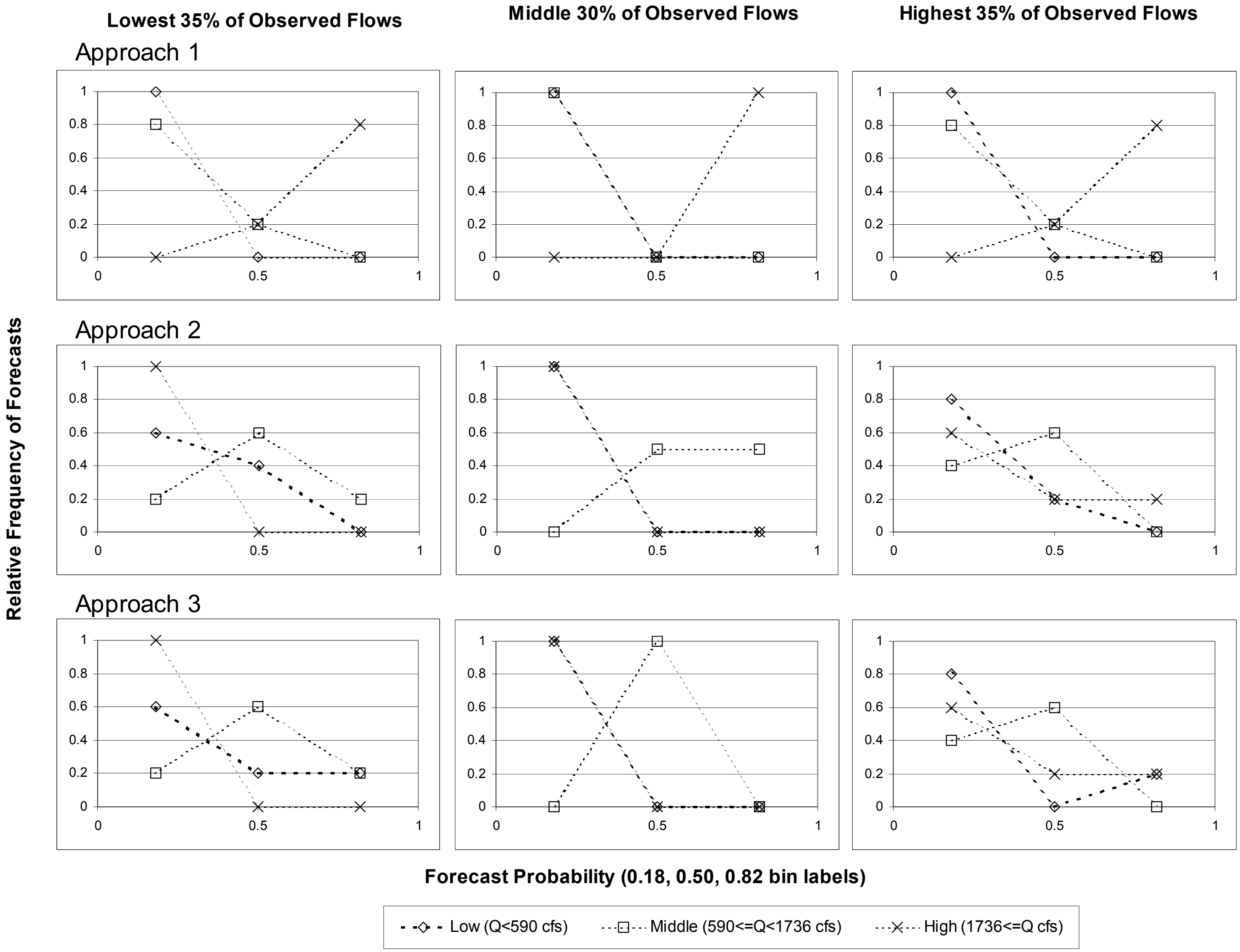


Figure E-5. Discrimination Plots for GRPC2, April 1, 90-day, Maximum Daily Flow

Table E-5. Discrimination Plot Data for GRPC2, April 1, 90-day, Maximum Daily Flow

GRPC2 April 1, 90-day Maximum Daily Flow: Approach 1

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	590.000	5	4	0	0	1	1	0	0	4
68	5	1.00	0.80	0.00	0.00	0.20	0.20	0.00	0.00	0.80
590.000	1736.000	6	6	0	0	0	0	0	0	6
32	6	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
1736.000		5	4	0	0	1	1	0	0	4
0	5	1.00	0.80	0.00	0.00	0.20	0.20	0.00	0.00	0.80

GRPC2 April 1, 90-day Maximum Daily Flow: Approach 2

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	590.000	3	1	5	2	3	0	0	1	0
68	5	0.60	0.20	1.00	0.40	0.60	0.00	0.00	0.20	0.00
590.000	1736.000	6	0	6	0	3	0	0	3	0
32	6	1.00	0.00	1.00	0.00	0.50	0.00	0.00	0.50	0.00
1736.000		4	2	3	1	3	1	0	0	1
0	5	0.80	0.40	0.60	0.20	0.60	0.20	0.00	0.00	0.20

GRPC2 April 1, 90-day Maximum Daily Flow: Approach 3

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	590.000	3	1	5	1	3	0	1	1	0
68	5	0.60	0.20	1.00	0.20	0.60	0.00	0.20	0.20	0.00
590.000	1736.000	6	0	6	0	6	0	0	0	0
32	6	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00
1736.000		4	2	3	0	3	1	1	0	1
0	5	0.80	0.40	0.60	0.00	0.60	0.20	0.20	0.00	0.20

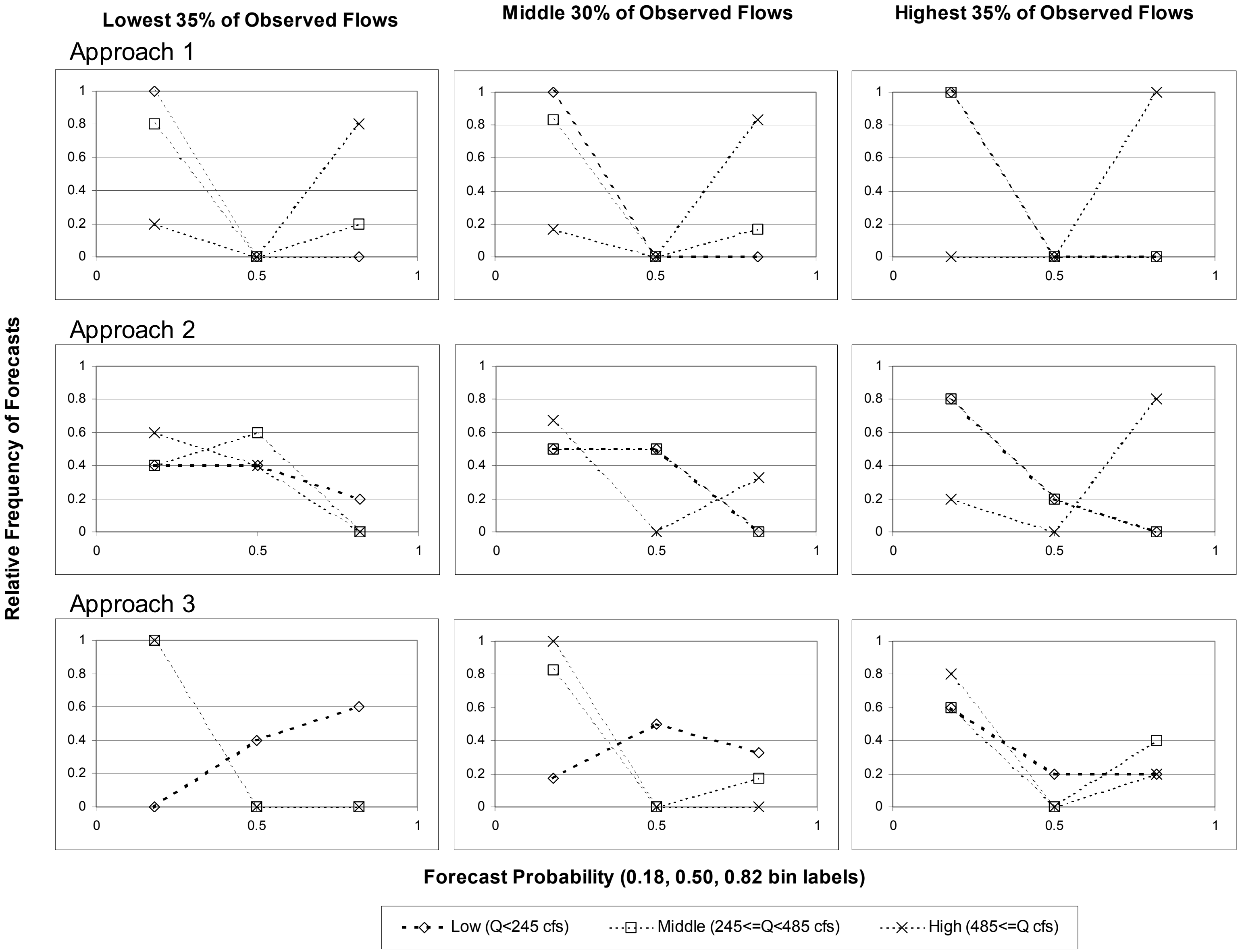


Figure E-6. Discrimination Plots for GRPC2, July 1, 90-day, Maximum Daily Flow

Table E-6. Discrimination Plot Data for GRPC2, July 1, 90-day, Maximum Daily Flow

GRPC2 July 1, 90-day Maximum Daily Flow: Approach 1

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	245.000	5	4	1	0	0	0	0	1	4
70	5	1.00	0.80	0.20	0.00	0.00	0.00	0.00	0.20	0.80
245.000	485.000	6	5	1	0	0	0	0	1	5
30	6	1.00	0.83	0.17	0.00	0.00	0.00	0.00	0.17	0.83
485.000		5	5	0	0	0	0	0	0	5
0	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

GRPC2 July 1, 90-day Maximum Daily Flow: Approach 2

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	245.000	2	2	3	2	3	2	1	0	0
70	5	0.40	0.40	0.60	0.40	0.60	0.40	0.20	0.00	0.00
245.000	485.000	3	3	4	3	3	0	0	0	2
30	6	0.50	0.50	0.67	0.50	0.50	0.00	0.00	0.00	0.33
485.000		4	4	1	1	1	0	0	0	4
0	5	0.80	0.80	0.20	0.20	0.20	0.00	0.00	0.00	0.80

GRPC2 July 1, 90-day Maximum Daily Flow: Approach 3

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	245.000	0	5	5	2	0	0	3	0	0
70	5	0.00	1.00	1.00	0.40	0.00	0.00	0.60	0.00	0.00
245.000	485.000	1	5	6	3	0	0	2	1	0
30	6	0.17	0.83	1.00	0.50	0.00	0.00	0.33	0.17	0.00
485.000		3	3	4	1	0	0	1	2	1
0	5	0.60	0.60	0.80	0.20	0.00	0.00	0.20	0.40	0.20

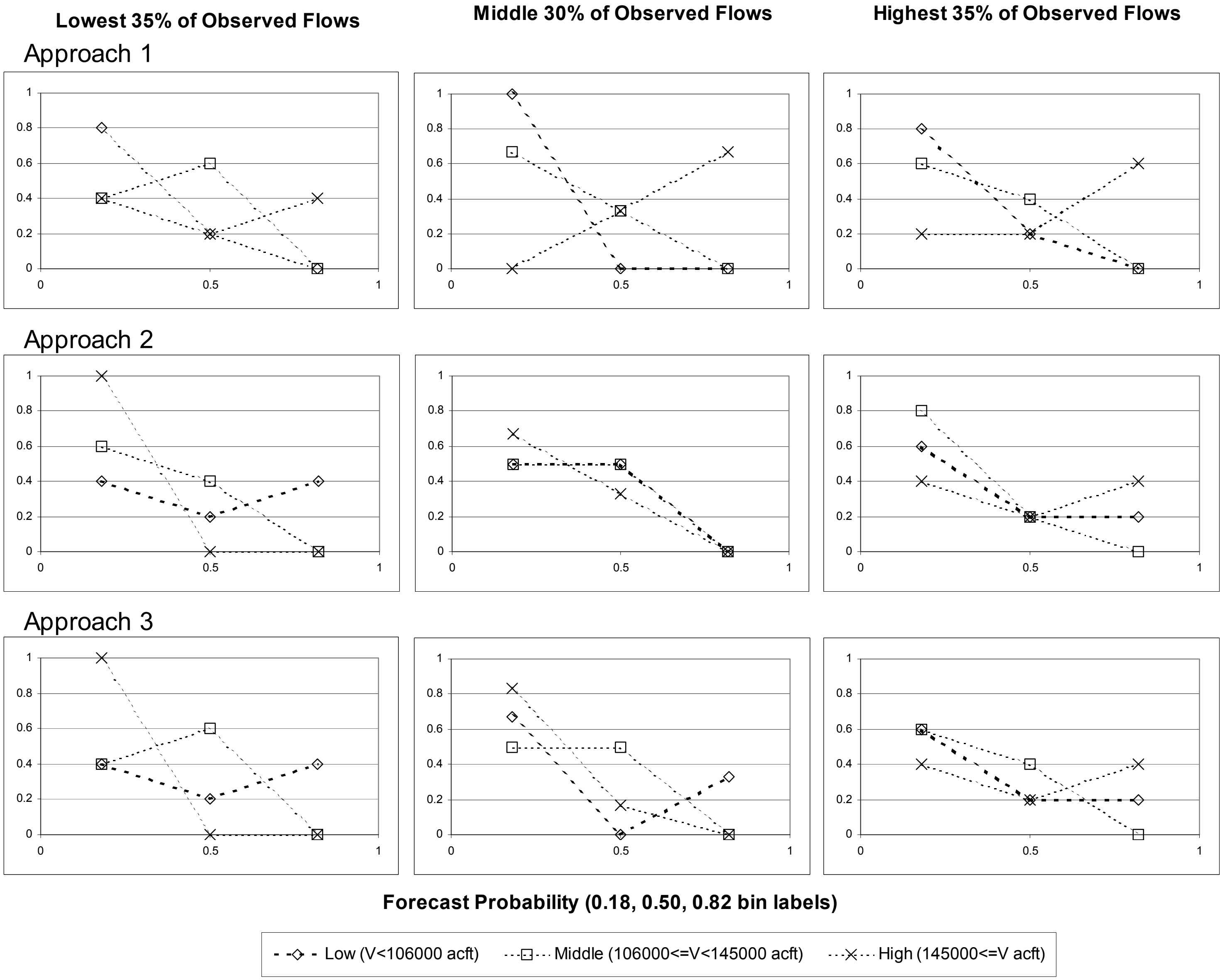


Figure E-7. Discrimination Plots for FTDC2, April 1, 90-day, Total Volume

Table E-7. Discrimination Plot Data for FTDC2, April 1, 90-day, Total Volume

FTDC2 April 1, 90-day Total Volume: Approach 1

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	106000.000			4	2	2	1	3	1	0	0	2
		70	5	0.80	0.40	0.40	0.20	0.60	0.20	0.00	0.00	0.40
106000.000	145000.000			6	4	0	0	2	2	0	0	4
		30	6	1.00	0.67	0.00	0.00	0.33	0.33	0.00	0.00	0.67
145000.000				4	3	1	1	2	1	0	0	3
		0	5	0.80	0.60	0.20	0.20	0.40	0.20	0.00	0.00	0.60

FTDC2 April 1, 90-day Total Volume: Approach 2

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	106000.000			2	3	5	1	2	0	2	0	0
		70	5	0.40	0.60	1.00	0.20	0.40	0.00	0.40	0.00	0.00
106000.000	145000.000			3	3	4	3	3	2	0	0	0
		30	6	0.50	0.50	0.67	0.50	0.50	0.33	0.00	0.00	0.00
145000.000				3	4	2	1	1	1	1	0	2
		0	5	0.60	0.80	0.40	0.20	0.20	0.20	0.20	0.00	0.40

FTDC2 April 1, 90-day Total Volume: Approach 3

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	106000.000			2	2	5	1	3	0	2	0	0
		70	5	0.40	0.40	1.00	0.20	0.60	0.00	0.40	0.00	0.00
106000.000	145000.000			4	3	5	0	3	1	2	0	0
		30	6	0.67	0.50	0.83	0.00	0.50	0.17	0.33	0.00	0.00
145000.000				3	3	2	1	2	1	1	0	2
		0	5	0.60	0.60	0.40	0.20	0.40	0.20	0.20	0.00	0.40

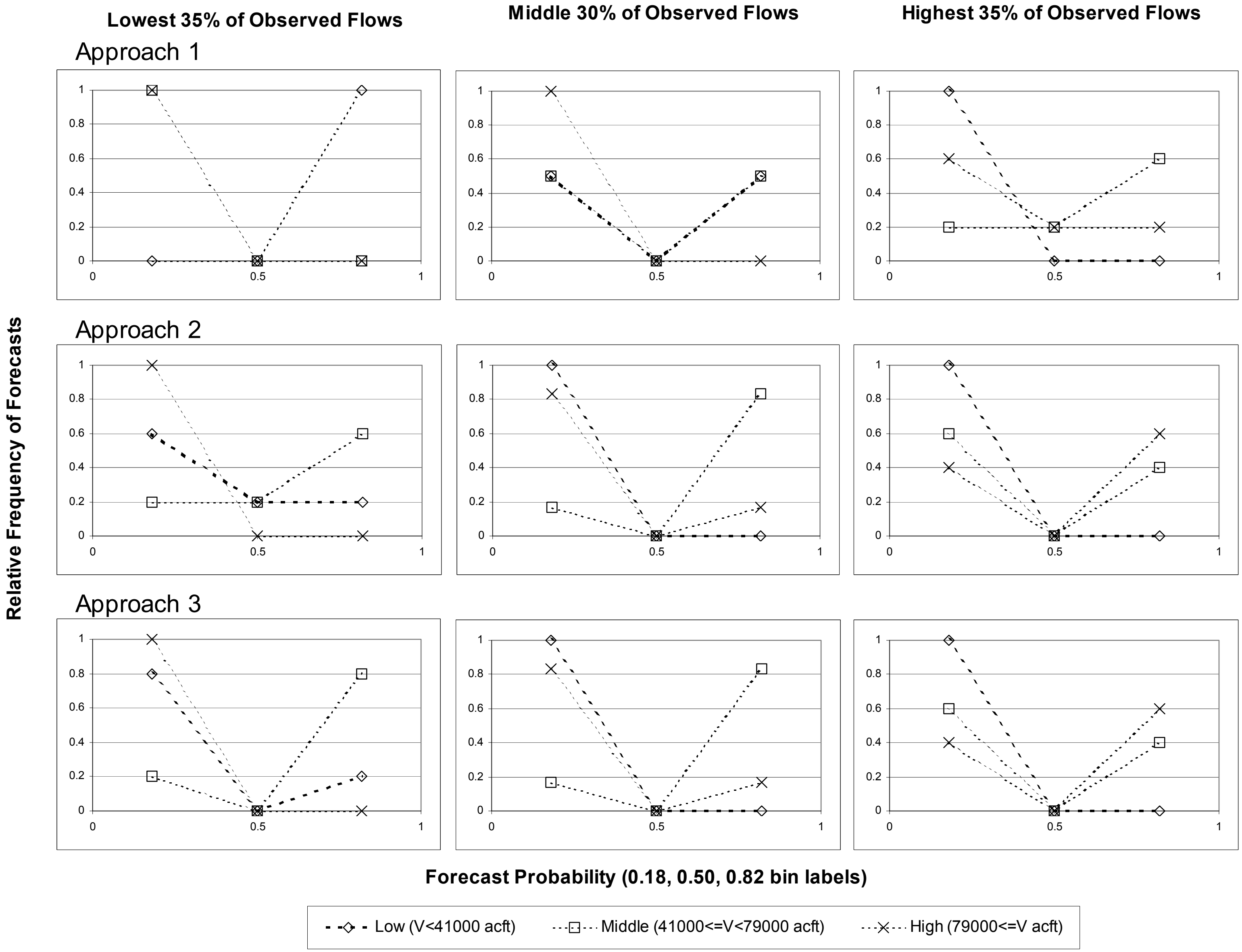


Figure E-8. Discrimination Plots for FTDC2, July 1, 90-day, Total Volume

Table E-8. Discrimination Plot Data for FTDC2, July 1, 90-day, Total Volume

```
FTDC2 July 1, 90-day Total Volume: Approach 1
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  41000.000 |    0    5    5 |    0    0    0 |    5    0    0
               67         5 | 0.00 1.00 1.00 | 0.00 0.00 0.00 | 1.00 0.00 0.00
       ---------------------+----------------+----------------+---------------
        41000.000 79000.000 |    3    3    6 |    0    0    0 |    3    3    0
               33         6 | 0.50 0.50 1.00 | 0.00 0.00 0.00 | 0.50 0.50 0.00
       ---------------------+----------------+----------------+---------------
        79000.000           |    5    1    3 |    0    1    1 |    0    3    1
                0         5 | 1.00 0.20 0.60 | 0.00 0.20 0.20 | 0.00 0.60 0.20

FTDC2 July 1, 90-day Total Volume: Approach 2
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  41000.000 |    3    1    5 |    1    1    0 |    1    3    0
               67         5 | 0.60 0.20 1.00 | 0.20 0.20 0.00 | 0.20 0.60 0.00
       ---------------------+----------------+----------------+---------------
        41000.000 79000.000 |    6    1    5 |    0    0    0 |    0    5    1
               33         6 | 1.00 0.17 0.83 | 0.00 0.00 0.00 | 0.00 0.83 0.17
       ---------------------+----------------+----------------+---------------
        79000.000           |    5    3    2 |    0    0    0 |    0    2    3
                0         5 | 1.00 0.60 0.40 | 0.00 0.00 0.00 | 0.00 0.40 0.60

FTDC2 July 1, 90-day Total Volume: Approach 3
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  41000.000 |    4    1    5 |    0    0    0 |    1    4    0
               67         5 | 0.80 0.20 1.00 | 0.00 0.00 0.00 | 0.20 0.80 0.00
       ---------------------+----------------+----------------+---------------
        41000.000 79000.000 |    6    1    5 |    0    0    0 |    0    5    1
               33         6 | 1.00 0.17 0.83 | 0.00 0.00 0.00 | 0.00 0.83 0.17
       ---------------------+----------------+----------------+---------------
        79000.000           |    5    3    2 |    0    0    0 |    0    2    3
                0         5 | 1.00 0.60 0.40 | 0.00 0.00 0.00 | 0.00 0.40 0.60
```

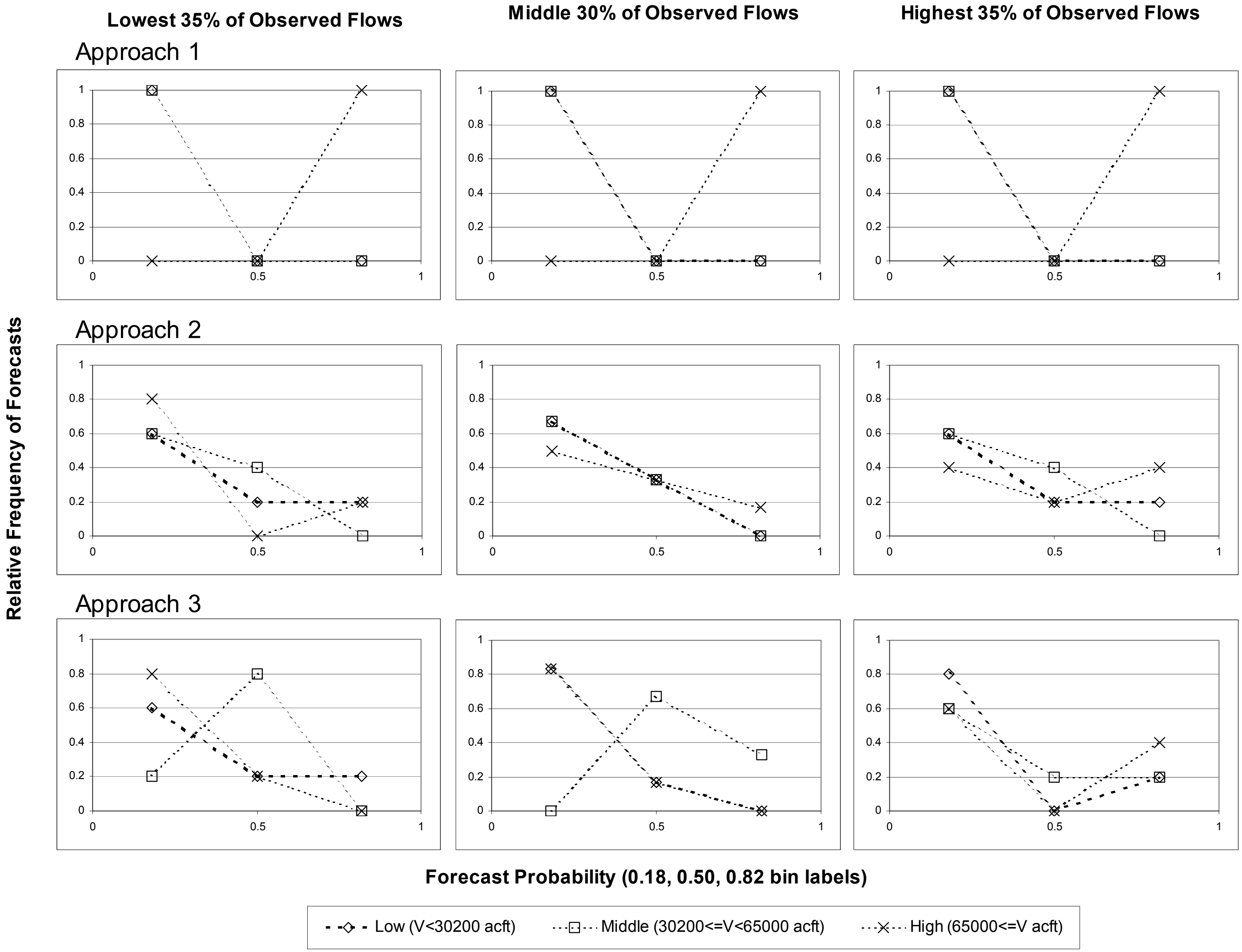


Figure E-9. Discrimination Plots for POUC2, April 1, 90-day, Total Volume

Table E-9. Discrimination Plot Data for POUC2, April 1, 90-day, Total Volume

```
POUC2 April 1, 90-day Total Volume: Approach 1
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  30200.000 |    5    5    0 |    0    0    0 |    0    0    5
                70        5 | 1.00 1.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 1.00
       ---------------------+----------------+----------------+---------------
        30200.000 65000.000 |    6    6    0 |    0    0    0 |    0    0    6
                30        6 | 1.00 1.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 1.00
       ---------------------+----------------+----------------+---------------
        65000.000           |    5    5    0 |    0    0    0 |    0    0    5
                 0        5 | 1.00 1.00 0.00 | 0.00 0.00 0.00 | 0.00 0.00 1.00
```

```
POUC2 April 1, 90-day Total Volume: Approach 2
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  30200.000 |    3    3    4 |    1    2    0 |    1    0    1
                70        5 | 0.60 0.60 0.80 | 0.20 0.40 0.00 | 0.20 0.00 0.20
       ---------------------+----------------+----------------+---------------
        30200.000 65000.000 |    4    4    3 |    2    2    2 |    0    0    1
                30        6 | 0.67 0.67 0.50 | 0.33 0.33 0.33 | 0.00 0.00 0.17
       ---------------------+----------------+----------------+---------------
        65000.000           |    3    3    2 |    1    2    1 |    1    0    2
                 0        5 | 0.60 0.60 0.40 | 0.20 0.40 0.20 | 0.20 0.00 0.40
```

```
POUC2 April 1, 90-day Total Volume: Approach 3
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  30200.000 |    3    1    4 |    1    4    1 |    1    0    0
                70        5 | 0.60 0.20 0.80 | 0.20 0.80 0.20 | 0.20 0.00 0.00
       ---------------------+----------------+----------------+---------------
        30200.000 65000.000 |    5    0    5 |    1    4    1 |    0    2    0
                30        6 | 0.83 0.00 0.83 | 0.17 0.67 0.17 | 0.00 0.33 0.00
       ---------------------+----------------+----------------+---------------
        65000.000           |    4    3    3 |    0    1    0 |    1    1    2
                 0        5 | 0.80 0.60 0.60 | 0.00 0.20 0.00 | 0.20 0.20 0.40
```

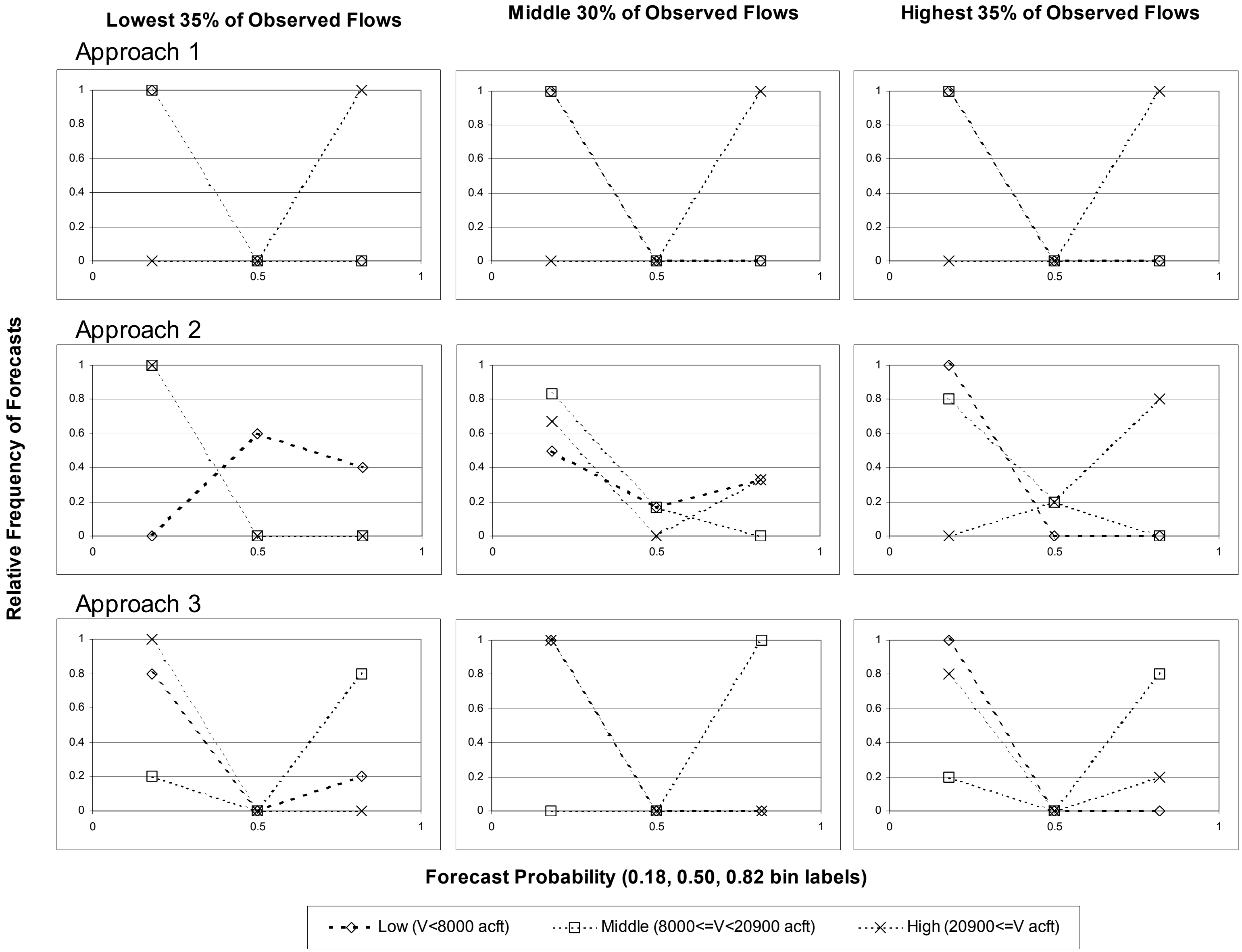


Figure E-10. Discrimination Plots for POUC2, July 1, 90-day, Total Volume

Table E-10. Discrimination Plot Data for POUC2, July 1, 90-day, Total Volume

POUC2 July 1, 90-day Total Volume: Approach 1

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	8000.000	5	5	0	0	0	0	0	0	5
69	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
8000.000	20900.000	6	6	0	0	0	0	0	0	6
31	6	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
20900.000		5	5	0	0	0	0	0	0	5
0	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

POUC2 July 1, 90-day Total Volume: Approach 2

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	8000.000	0	5	5	3	0	0	2	0	0
69	5	0.00	1.00	1.00	0.60	0.00	0.00	0.40	0.00	0.00
8000.000	20900.000	3	5	4	1	1	0	2	0	2
31	6	0.50	0.83	0.67	0.17	0.17	0.00	0.33	0.00	0.33
20900.000		5	4	0	0	1	1	0	0	4
0	5	1.00	0.80	0.00	0.00	0.20	0.20	0.00	0.00	0.80

POUC2 July 1, 90-day Total Volume: Approach 3

Observations From C1	to < C2	0% to < 35%			35% to < 65%			65% to <100%		
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	8000.000	4	1	5	0	0	0	1	4	0
69	5	0.80	0.20	1.00	0.00	0.00	0.00	0.20	0.80	0.00
8000.000	20900.000	6	0	6	0	0	0	0	6	0
31	6	1.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00
20900.000		5	1	4	0	0	0	0	4	1
0	5	1.00	0.20	0.80	0.00	0.00	0.00	0.00	0.80	0.20

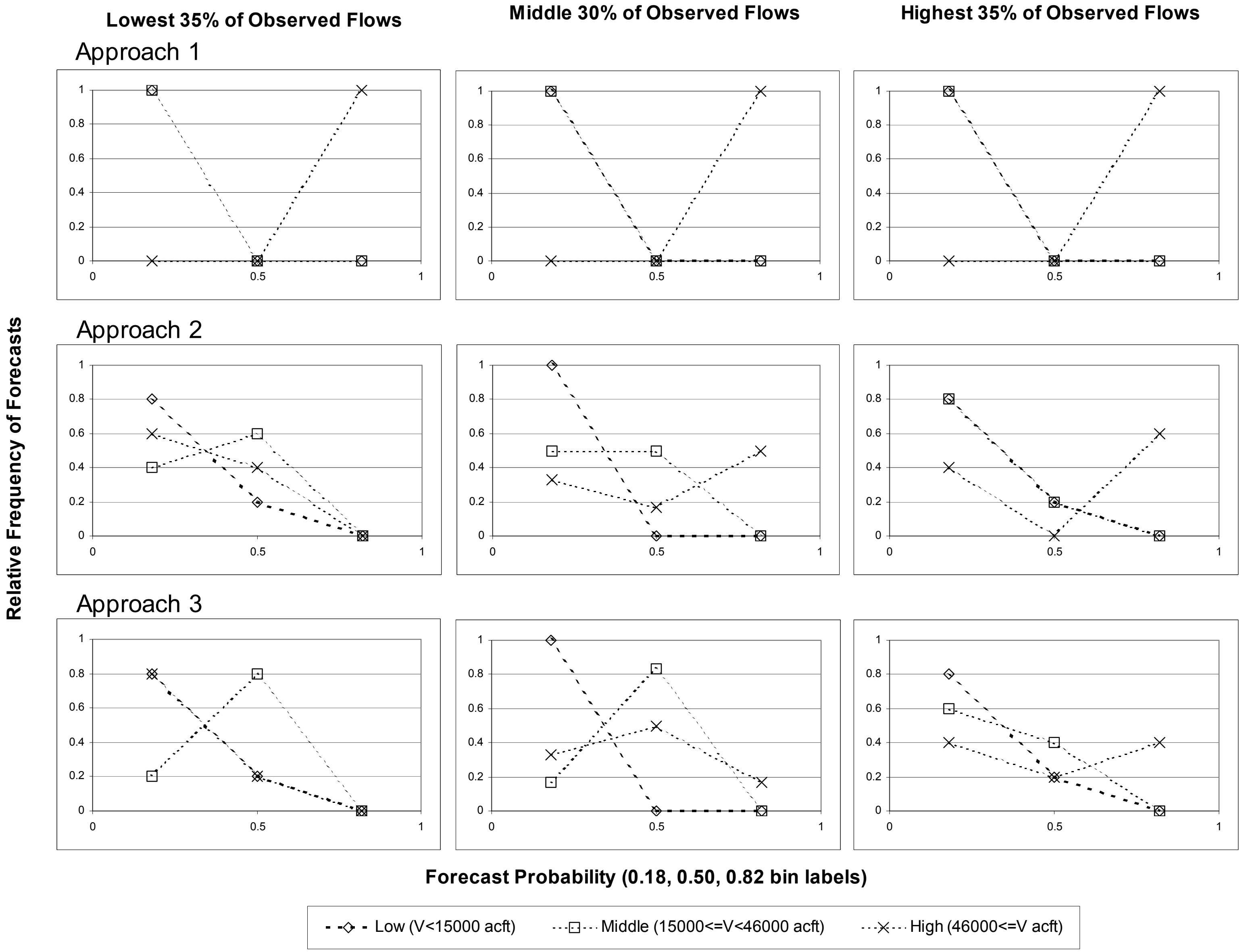


Figure E-11. Discrimination Plots for GRPC2, April 1, 90-day, Total Volume

Table E-11. Discrimination Plot Data for GRPC2, April 1, 90-day, Total Volume

GRPC2 April 1, 90-day Total Volume: Approach 1

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	15000.000			5	5	0	0	0	0	0	0	5
		70	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
15000.000	46000.000			6	6	0	0	0	0	0	0	6
		30	6	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
46000.000				5	5	0	0	0	0	0	0	5
		0	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

GRPC2 April 1, 90-day Total Volume: Approach 2

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	15000.000			4	2	3	1	3	2	0	0	0
		70	5	0.80	0.40	0.60	0.20	0.60	0.40	0.00	0.00	0.00
15000.000	46000.000			6	3	2	0	3	1	0	0	3
		30	6	1.00	0.50	0.33	0.00	0.50	0.17	0.00	0.00	0.50
46000.000				4	4	2	1	1	0	0	0	3
		0	5	0.80	0.80	0.40	0.20	0.20	0.00	0.00	0.00	0.60

GRPC2 April 1, 90-day Total Volume: Approach 3

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	15000.000			4	1	4	1	4	1	0	0	0
		70	5	0.80	0.20	0.80	0.20	0.80	0.20	0.00	0.00	0.00
15000.000	46000.000			6	1	2	0	5	3	0	0	1
		30	6	1.00	0.17	0.33	0.00	0.83	0.50	0.00	0.00	0.17
46000.000				4	3	2	1	2	1	0	0	2
		0	5	0.80	0.60	0.40	0.20	0.40	0.20	0.00	0.00	0.40

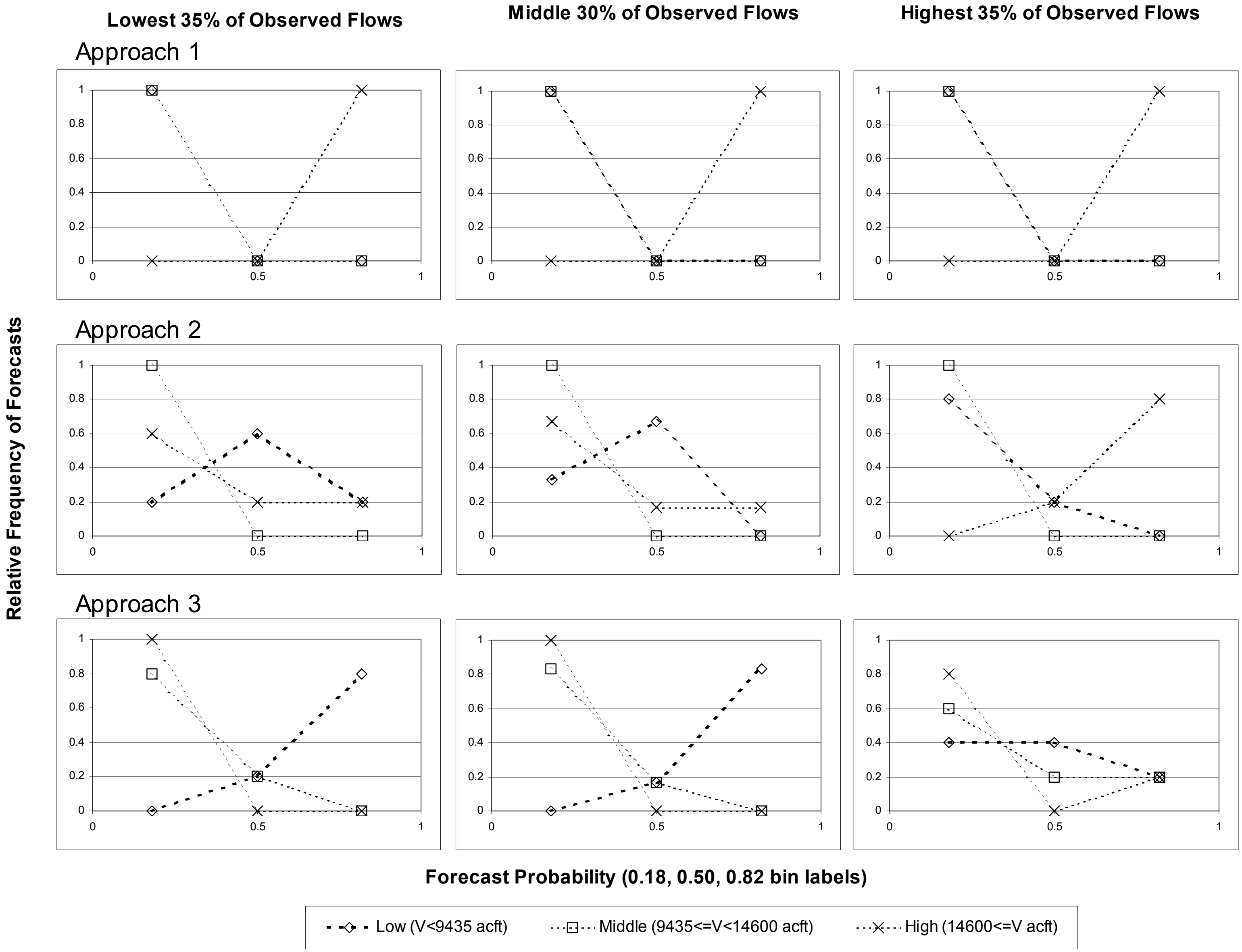


Figure E-12. Discrimination Plots for GRPC2, July 1, 90-day, Total Volume

Table E-12. Discrimination Plot Data for GRPC2, July 1, 90-day, Total Volume

GRPC2 July 1, 90-day Total Volume: Approach 1

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	9435.000			5	5	0	0	0	0	0	0	5
		70	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
9435.000	14600.000			6	6	0	0	0	0	0	0	6
		30	6	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
14600.000				5	5	0	0	0	0	0	0	5
		0	5	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

GRPC2 July 1, 90-day Total Volume: Approach 2

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	9435.000			1	5	3	3	0	1	1	0	1
		70	5	0.20	1.00	0.60	0.60	0.00	0.20	0.20	0.00	0.20
9435.000	14600.000			2	6	4	4	0	1	0	0	1
		30	6	0.33	1.00	0.67	0.67	0.00	0.17	0.00	0.00	0.17
14600.000				4	5	0	1	0	1	0	0	4
		0	5	0.80	1.00	0.00	0.20	0.00	0.20	0.00	0.00	0.80

GRPC2 July 1, 90-day Total Volume: Approach 3

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	9435.000			0	4	5	1	1	0	4	0	0
		70	5	0.00	0.80	1.00	0.20	0.20	0.00	0.80	0.00	0.00
9435.000	14600.000			0	5	6	1	1	0	5	0	0
		30	6	0.00	0.83	1.00	0.17	0.17	0.00	0.83	0.00	0.00
14600.000				2	3	4	2	1	0	1	1	1
		0	5	0.40	0.60	0.80	0.40	0.20	0.00	0.20	0.20	0.20

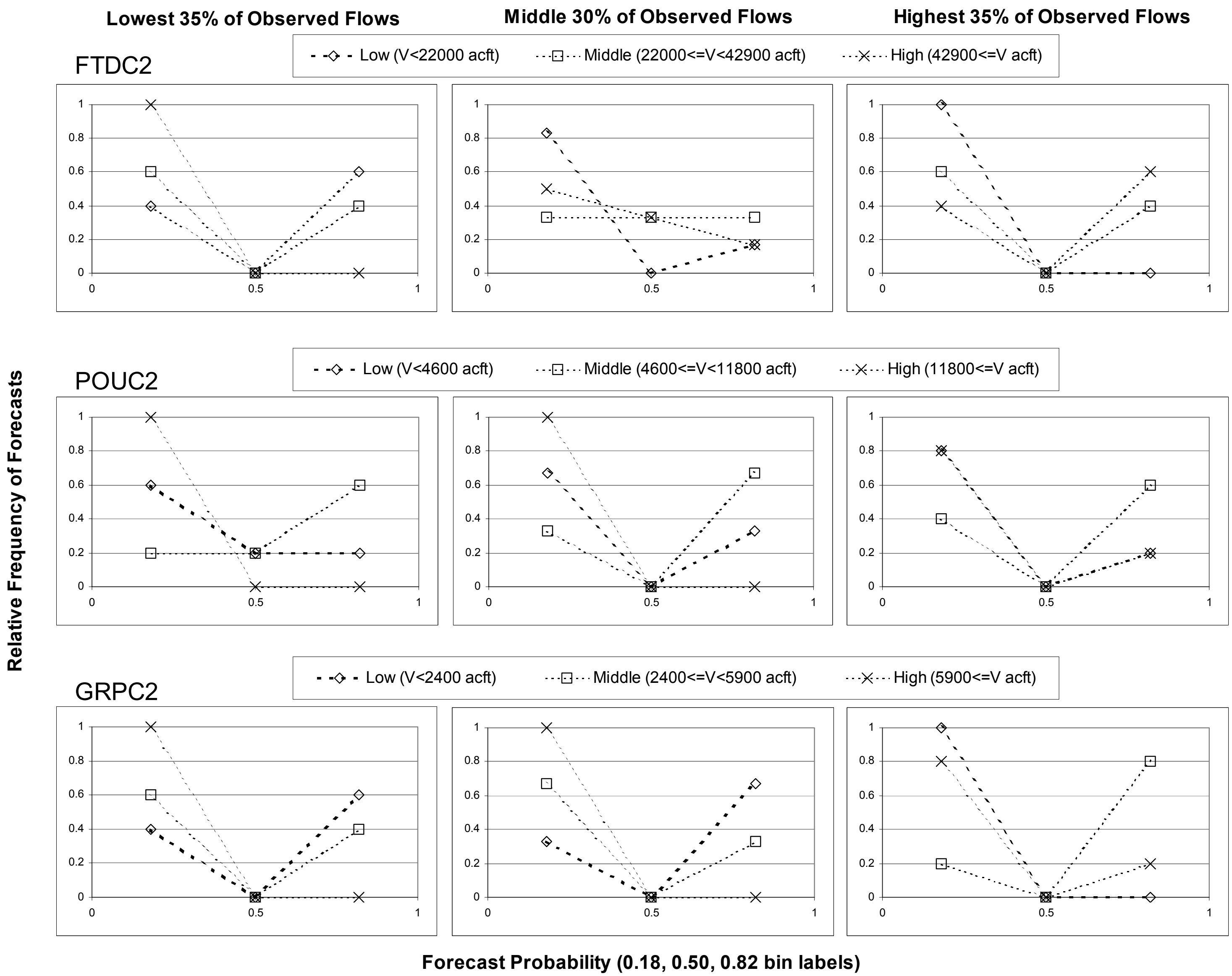


Figure E-13. Discrimination Plots for Approach 3, July 1, 30-day, Total Volume

Table E-13. Discrimination Plot Data for Approach 3, July 1, 30-day, Total Volume

Approach 3 July 1, 30-day Total Volume: FTDC2

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	22000.000			2	3	5	0	0	0	3	2	0
		69	5	0.40	0.60	1.00	0.00	0.00	0.00	0.60	0.40	0.00
22000.000	42900.000			5	2	3	0	2	2	1	2	1
		31	6	0.83	0.33	0.50	0.00	0.33	0.33	0.17	0.33	0.17
42900.000				5	3	2	0	0	0	0	2	3
		0	5	1.00	0.60	0.40	0.00	0.00	0.00	0.00	0.40	0.60

Approach 3 July 1, 30-day Total Volume: POUC2

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	4600.000			3	1	5	1	1	0	1	3	0
		67	5	0.60	0.20	1.00	0.20	0.20	0.00	0.20	0.60	0.00
4600.000	11800.000			4	2	6	0	0	0	2	4	0
		33	6	0.67	0.33	1.00	0.00	0.00	0.00	0.33	0.67	0.00
11800.000				4	2	4	0	0	0	1	3	1
		0	5	0.80	0.40	0.80	0.00	0.00	0.00	0.20	0.60	0.20

Approach 3 July 1, 30-day Total Volume: GRPC2

Observations From C1	to < C2	%	# Obs	0% to < 35% F0	F1	F2	35% to < 65% F0	F1	F2	65% to <100% F0	F1	F2
	2400.000			2	3	5	0	0	0	3	2	0
		70	5	0.40	0.60	1.00	0.00	0.00	0.00	0.60	0.40	0.00
2400.000	5900.000			2	4	6	0	0	0	4	2	0
		30	6	0.33	0.67	1.00	0.00	0.00	0.00	0.67	0.33	0.00
5900.000				5	1	4	0	0	0	0	4	1
		0	5	1.00	0.20	0.80	0.00	0.00	0.00	0.00	0.80	0.20

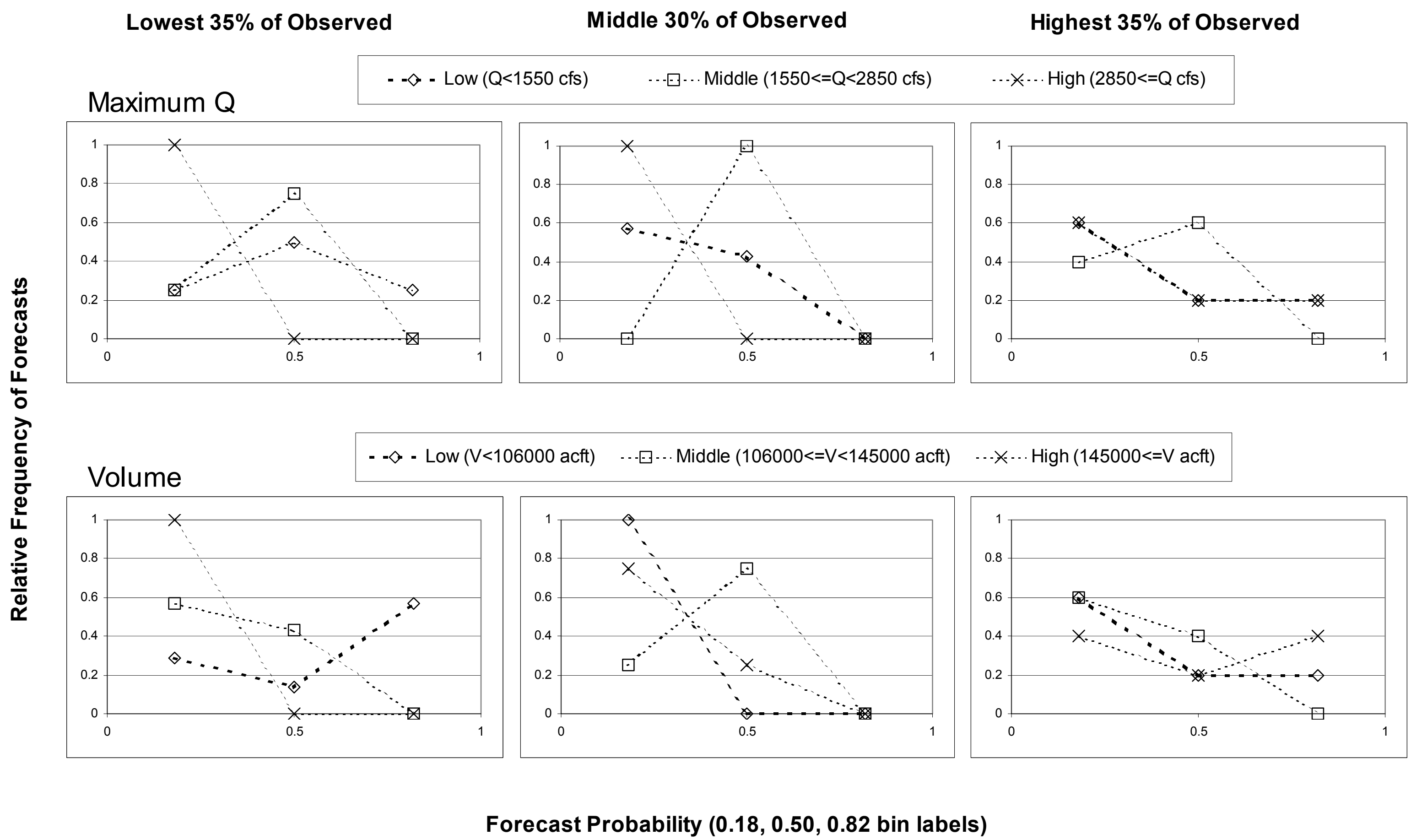


Figure E-14. Discrimination Plots for FTDC2, April 1, 90-day Maximum Flow and Total Volume—Simulated Time Series As Observation

Table E-14. Discrimination Plot Data for FTDC2, April 1, 90-day Maximum Flow and Total Volume—Simulated Time Series As Observation

Approach 3 FTDC2 April 1, 90-day - Simulated Time Series as Observation: Maximum Flow

Observations		0% to < 35%			35% to < 65%			65% to <100%		
From C1	to < C2									
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	1550.000	1	1	4	2	3	0	1	0	0
69	4	0.25	0.25	1.00	0.50	0.75	0.00	0.25	0.00	0.00
1550.000	2850.000	4	0	7	3	7	0	0	0	0
31	7	0.57	0.00	1.00	0.43	1.00	0.00	0.00	0.00	0.00
2850.000		3	2	3	1	3	1	1	0	1
0	5	0.60	0.40	0.60	0.20	0.60	0.20	0.20	0.00	0.20

Approach 3 FTDC2 April 1, 90-day - Simulated Time Series as Observation: Total Volume

Observations		0% to < 35%			35% to < 65%			65% to <100%		
From C1	to < C2									
%	# Obs	F0	F1	F2	F0	F1	F2	F0	F1	F2
	106000.000	2	4	7	1	3	0	4	0	0
65	7	0.29	0.57	1.00	0.14	0.43	0.00	0.57	0.00	0.00
106000.000	145000.000	4	1	3	0	3	1	0	0	0
35	4	1.00	0.25	0.75	0.00	0.75	0.25	0.00	0.00	0.00
145000.000		3	3	2	1	2	1	1	0	2
0	5	0.60	0.60	0.40	0.20	0.40	0.20	0.20	0.00	0.40

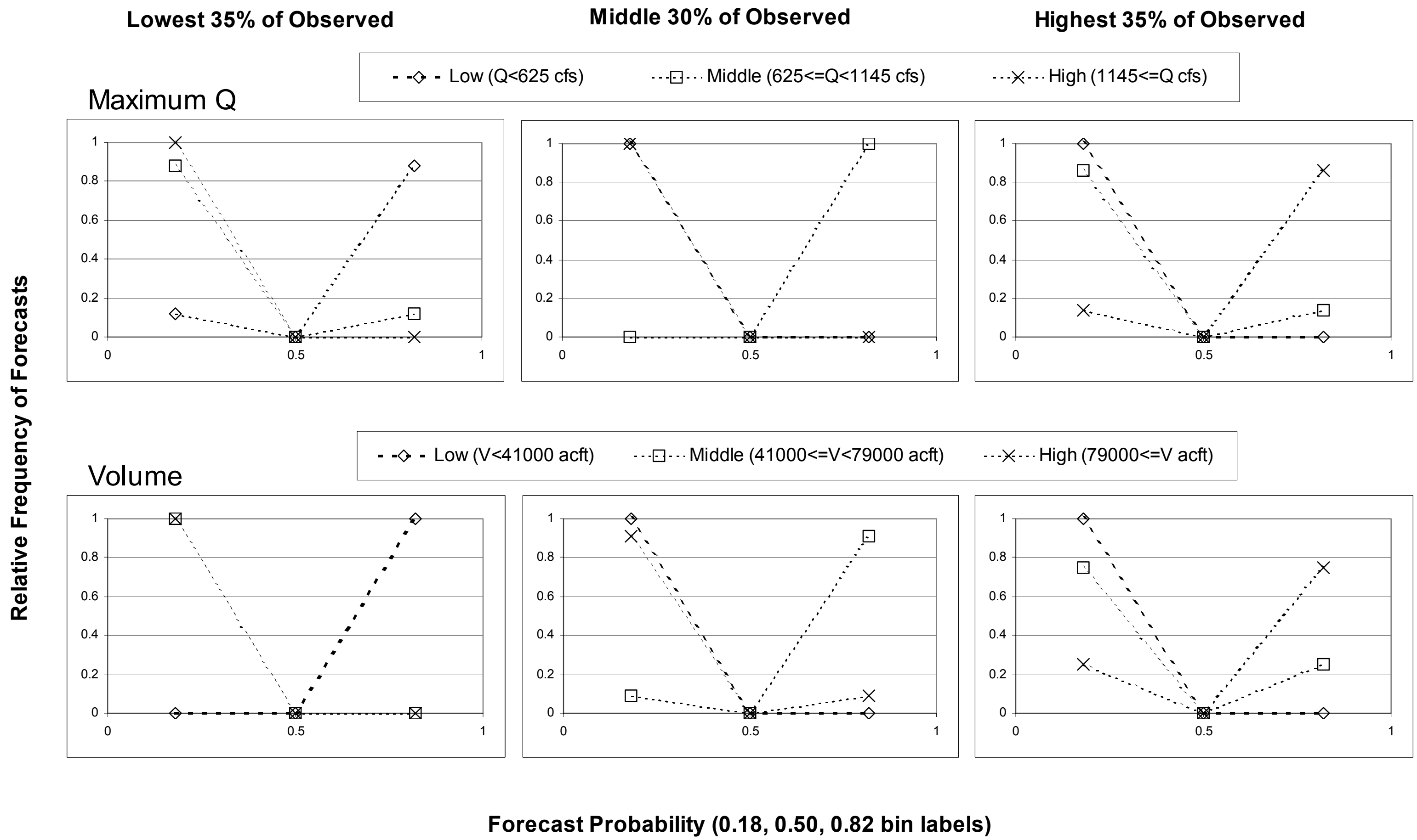


Figure E-15. Discrimination Plots for FTDC2, July 1, 90-day Maximum Flow and Total Volume—Simulated Time Series As Observation

Table E-15. Discrimination Plot Data for FTDC2, July 1, 90-day Maximum Flow and Total Volume—Simulated Time Series As Observation

```
Approach 3 FTDC2 July 1, 90-day - Simulated Time Series as Observation: Maximum Flow
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                    625.000 |    1    7    8 |    0    0    0 |    7    1    0
                57        8 | 0.12 0.88 1.00 | 0.00 0.00 0.00 | 0.88 0.12 0.00
       ---------------------+----------------+----------------+---------------
          625.000  1145.000 |    1    0    1 |    0    0    0 |    0    1    0
                43        1 | 1.00 0.00 1.00 | 0.00 0.00 0.00 | 0.00 1.00 0.00
       ---------------------+----------------+----------------+---------------
         1145.000           |    7    6    1 |    0    0    0 |    0    1    6
                 0        7 | 1.00 0.86 0.14 | 0.00 0.00 0.00 | 0.00 0.14 0.86

Approach 3 FTDC2 July 1, 90-day - Simulated Time Series as Observation: Total Volume
          Observations      |    0% to < 35% |   35% to < 65% |   65% to <100%
          From C1  to  < C2 |----------------+----------------+---------------
                %     # Obs | F0   F1   F2   | F0   F1   F2   | F0   F1   F2
       ---------------------+----------------+----------------+---------------
                  41000.000 |    0    1    1 |    0    0    0 |    1    0    0
                73        1 | 0.00 1.00 1.00 | 0.00 0.00 0.00 | 1.00 0.00 0.00
       ---------------------+----------------+----------------+---------------
        41000.000 79000.000 |   11    1   10 |    0    0    0 |    0   10    1
                27       11 | 1.00 0.09 0.91 | 0.00 0.00 0.00 | 0.00 0.91 0.09
       ---------------------+----------------+----------------+---------------
        79000.000           |    4    3    1 |    0    0    0 |    0    1    3
                 0        4 | 1.00 0.75 0.25 | 0.00 0.00 0.00 | 0.00 0.25 0.75
```